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Phosphate Rock Availability—Domestic

A Minerals Availability Program Appraisal

By R. J. Fantel, D. E. Sullivan, and G. R. Peterson

UNITED STATES DEPARTMENT OF THE INTERIOR

(United States. Bureau of Mines)

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UNITED STATES DEPARTMENT OF THE INTERIOR
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PREFACE

The Bureau of Mines is assessing the worldwide availability of nonfuel minerals. The Bureau identifies, collects, compiles, and evaluates information on active, developed, and explored mines and deposits, and on mineral processing plants worldwide. Objectives are to classify domestic and foreign resources; to identify by cost evaluation, resources that are reserves; and to prepare analyses of mineral availabilities.

This report is part of a continuing series of reports that analyze the availability of minerals from domestic and foreign sources and the factors affecting availability. Analyses of other minerals are in progress. Questions about these reports should be addressed to Chief, Division of Minerals Availability, Bureau of Mines, 2401 E St., NW., Washington, D.C. 20241.

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A Minerals Availability Program Appraisal

By R. J. Fantel,[1] D. E. Sullivan,[2] and G. R. Peterson[3]

ABSTRACT

To determine the availability of phosphate rock from domestic resources, the Bureau of Mines evaluated the potential production of phosphate rock from the demonstrated resources of 130 mines and deposits. The evaluation included an estimation of resources, engineering methods, and capital and operating costs, and an economic analysis to determine each operation's average total cost of production over the life of the mine, including a 15-pct discounted-cash-flow rate of return on all investments. Quantified but not evaluated in this report are substantial phosphate resources at the inferred and hypothetical resource levels.

The 130 mines and deposits contain 6.4 billion tons of recoverable phosphate rock product, about 20 pct from producing mines. At total production costs of under $30 per ton in January 1981 dollars, about 1.3 billion tons of phosphate rock product is potentially available, over 90 pct from producing mines. This study suggests that production from low-cost, high-grade phosphate mines now in operation will decline during the next decade, and new higher cost, lower grade mines will have to be developed to satisfy demand into the next century.

In addition to the demonstrated resources evaluated in this study, 7 billion tons of inferred-level and 24 billion tons of hypothetical-level phosphate rock are potentially recoverable, which, in part, includes material containing high amounts of magnesium. Much of this material could likely become available in the near future.

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[2]Economist.
[3]Mineral economist.
Authors are with the Minerals Availability Field Office, Bureau of Mines, Denver, Colo.

INTRODUCTION

Nitrogen, phosphorus, and potassium are the three primary nutrients necessary for plant growth. When these elements are either lacking or depleted from the soil, their addition is necessary to obtain higher agricultural yields. The only practical commercial source of phosphorus is phosphate rock.

Phosphate ore consists of the calcium phosphate mineral apatite with quartz, calcite, and dolomite, along with clay and iron oxide minerals as the gangue. Industry practice, which is followed in this study, uses "phosphate rock" to refer to the beneficiated product of phosphate ore rather than to the in situ material. After beneficiation, phosphate rock ranges from 26 to about 34 pct P_2O_5 (phosphorus pentoxide). Phosphate rock can be converted to phosphoric acid by the chemical "wet" process, or to elemental phosphorus in an electric furnace. The quality of phosphate rock for the

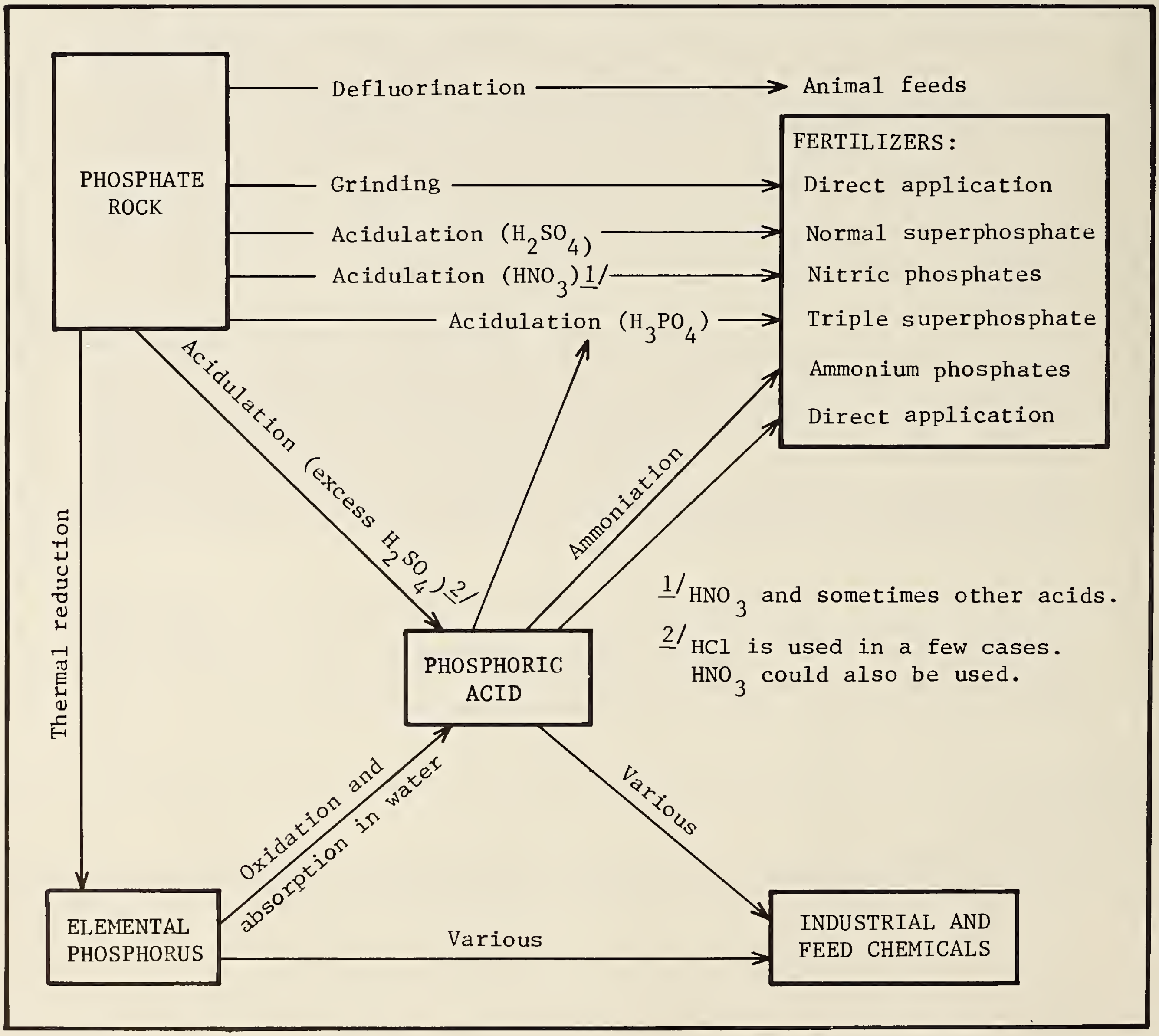

FIGURE 1. - Phosphate rock uses. *(Courtesy Stanford Research Institute International.)*

"wet" process is affected by the contained amounts of aluminum, iron, and magnesium. Presently, phosphate rock containing more than about 1.0 pct magnesium oxide or more than about 3.5 pct iron oxide plus aluminum oxide may cause problems in the mnaufacture of acids.

Phosphate rock (fig. 1) is used to produce wet-process phosphoric acid, electric furnace elemental phosphorus, and animal feed supplements, and is ground for direct application to acidic soil (2).[4] Phosphoric acid can be converted to ammonium phosphates and other fertilizers. Figure 2 illustrates the consumption pattern of phosphate rock in the United States in 1980. Nearly 90 pct of the phosphate rock consumed in that year was used in agriculture, mainly in the manufacture of phosphoric acids for fertilizer (9). Of key importance is the fact that phosphorus is not recovered by recycling; hence, the total supply must come from the mine production of phosphate rock. No substitute for phosphate fertilizers can be produced in the quantities required to sustain world agricultural production.

[4]Underlined numbers in parentheses refer to items in the list of references preceding the appendixes at the end of this report.

TABLE 1. - U.S. phosphate rock production,[1] million metric tons

	1960	1970	1980
Southeastern States[2]...	12.5	28.4	47.2
Tennessee..............	2.0	2.9	1.6
Western States[3]........	3.3	3.9	5.6
Total.............	17.8	35.2	54.4

[1]Phosphate rock refers to beneficiated product.
[2]Florida and North Carolina.
[3]Idaho, Utah, Montana, Wyoming, and California (1970).
Sources: Stowasser (14); Bureau of Mines Mineral Industry Surveys, Marketable Phosphate Rock--February 1981; and the Phosphate Rock chapters of the 1962 and 1971 editions of the Bureau of Mines Minerals Yearbook (v. 1).

The United States produced over 54 million tons[5] of phosphate rock in 1980 (table 1), accounting for approximately 40 pct of total world output. Approximately 26 pct of this production was exported and an additional 33 pct was converted to wet acid and exported as fertilizer and chemicals (16). The other two main phosphate rock producers are the U.S.S.R. and Morocco, which produced

[5]Unless otherwise noted, "tons" in the report refers to metric tons.

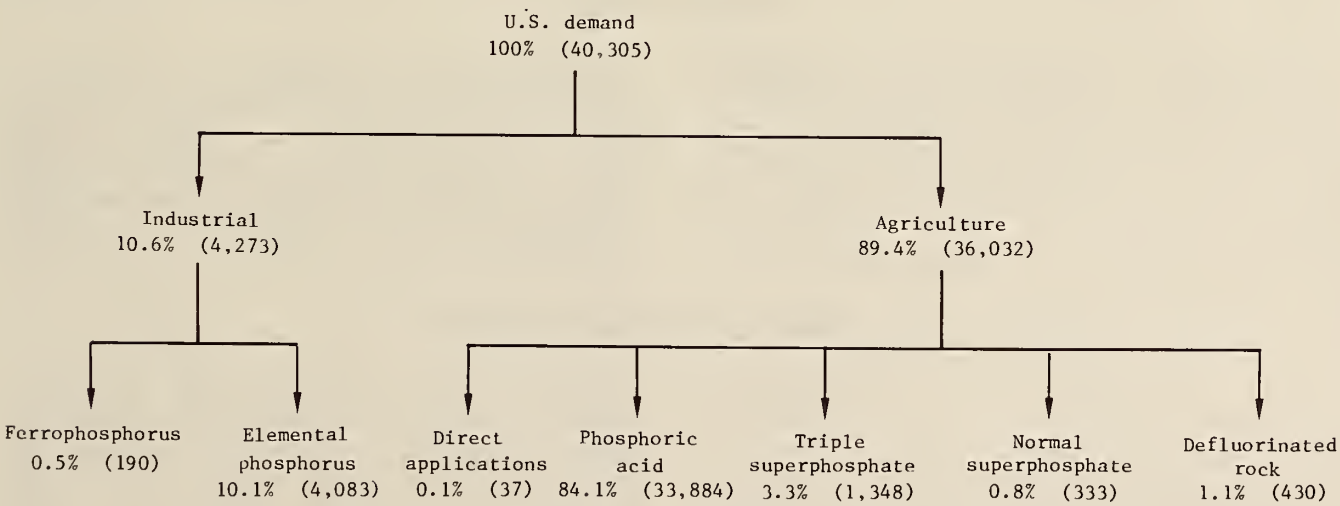

FIGURE 2. - Domestic phosphate rock consumed in 1980, in thousand metric tons. (Modified from reference 9 with data from reference 13, table 6.)

approximately 25 and 21 million tons of phosphate rock, respectively. Cumulatively, these three countries accounted for approximately three-fourths of world production in 1980. Although the U.S. Government does not maintain a phosphate rock stockpile, private companies maintain stockpiles which may amount to about 25 pct of production.

The major foreign markets for phosphate rock are Western and Eastern Europe and Asia. In 1978, Western Europe imported more than 21 million tons, Eastern Europe more than 10 million tons, and countries in Asia almost 7 million tons.

In the United States phosphate is traded both as rock product and in the upgraded chemical forms. Although in the past Morocco produced primarily phosphate rock, processing facilities are being expanded to increase phosphoric acid and processed phosphate production.

Phosphate rock produced in Florida and North Carolina is suitable for manufacturing phosphoric acid and fertilizer (although rock in North Carolina requires calcining). Phosphate rock produced in Tennessee is processed in electric furnaces to elemental phosphorus. Some acid-grade phosphate rock produced in Idaho, Utah, and Montana is also calcined before processing to produce acids. Furnace-grade phosphate rock produced in the West is reduced from the ore to elemental phosphorus in electric furnaces.

The United States has traditionally been the world's largest net exporter of phosphate rock and related fertilizer products. Over the past several years, however, continuing exports of phosphate rock from Florida have become the subject of controversy. Some industry sources content that Florida has enough phosphate to supply the domestic and export markets for almost 300 years at current rates of production, assuming a gradually rising price and using present and new technology (11). Conversely, William Stowasser, Bureau of Mines Phosphate Commodity Specialist and the General Accounting Office (GAO) forecast that by the turn of the century the United States may cease exporting phosphate rock (11).

This report is part of a continuing series in which the availibility of minerals from domestic and foreign sources and the factors affecting availability are analyzed. The importance of phosphorus in agricultural production underscores the need to determine the potential availability of phosphate rock from domestic resources.

ACKNOWLEDGMENTS

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THE DOMESTIC PHOSPHATE INDUSTRY

Most of the phosphate rock produced in the United States is used to manufacture wet-process phosphoric acid. Because phosphate rock is relatively low in water solubility, it is converted to chemical components for fertilizer application. The wet process produces phosphoric acid by digesting the apatite mineral in sulfuric acid. Diammonium phosphate (DAP), a common bulk blending-grade fertilizer chemical, is produced by reacting phosphoric acid with ammonia. If the phosphate rock is attacked with phosphoric acid, triple superphosphate (TSP) is produced. When wet-process phosphoric acid is subjected to evaporation, a

higher concentration of phosphoric acid is produced; when reacted with ammonia, phosphoric acid produces a liquid ammonium phosphate fertilizer (23).

The Midwestern States (particularly the Corn Belt) consume approximately half of all the fertilizer used in the United States. The other half is split nearly evenly between the Western and Eastern States. Phosphate fertilizer is consumed mainly to produce beans, corn, cotton, cereal grains, and soybeans (9).

Phosphate animal feed supplements are produced by the defluorinization of either phosphate rock or phosphoric acid. Lime is reacted with defluorinated phosphoric acid to produce dicalcium phosphate. These phosphate animal feeds are used to increase the nutritional quality of livestock feed (23).

Elemental phosphorus is produced by reducing phosphate rock in an electric furnace plant and marketed as is, or oxidized to produce phosphoric acid and anhydrous derivatives. Approximately 50 pct of elemental phosphorus produced is used to produce sodium tripolyphosphate, a detergent builder.

The potential byproducts fluorine, phosphogypsum, uranium, and vanadium in phosphate rock were not considered in this study.

More than 20 companies mined and processed phosphate rock in the United States in 1980. Firms in Florida and North Carolina include Agrico Chemical Co., Amax Phosphate, Inc., Brewster Phosphates, C. F. Industries, Inc., Gardinier, Inc., W. R. Grace and Co., International Minerals and Chemical Corp. (IMC), Mobil Chemical Co., Estech General Chemical Co., USS Agri-Chemicals, Occidental Chemical Co., and Texasgulf, Inc; those in Idaho, Montana, and Utah are Conda Partnership, Monsanto Industrial Chemicals, J. R. Simplot Co., Stauffer Chemical Co., Cominco American, Inc., and Chevron U.S.A.; Tennessee firms include Hooker Chemical Co., Monsanto Industrial Chemicals Co., and Stauffer Chemical Co. (16).

Other companies are presently developing domestic deposits, some of which produced in 1981-82, and others of which will be producing in the near future. They include Beker Phosphate Corp. Farmland Industries, Inc., in Florida, and North Carolina Phosphate Corp. in North Carolina. Numerous other companies have explored deposits throughout the United States, many of which were considered in this study (appendix A).

The domestic phosphate industry exhibits a high degree of vertical integration and is highly concentrated: 15 companies supplied over 95 pct of the country's phosphate rock production during the 1970's (14, p. 3).

Once mined and beneficiated, phosphate rock is transported either to a phosphoric acid or elemental phosphorus plant, or to a port for export. The rock is most commonly shipped by rail, although occasionally it is shipped by truck or slurry pipeline for short distances, or by barge for seaway hauls.

In Florida, most rock is sent either to nearby acid plants or directly to the port of Tampa for export or shipment to domestic users; some also goes to port at Jacksonville. Products from the acid plants are also shipped by rail to the ports of Tampa or Jacksonville for either export or shipment to domestic users. Most of the rock mined in Florida is processed within the State. In North Carolina, most of the rock is used to manufacture phosphoric acids for export or shipment to domestic users from the port at Morehead City.

In 1978 approximately 70 pct of Florida and North Carolina rock was used for domestic markets (mainly in the East and Midwest), and the remaining 30 pct was exported (9).

All phosphate rock in Tennessee is used to manufacture elemental phosphorus at plants in the Columbia and Mount Pleasant, Tenn., areas.

In Idaho, phosphate rock is used to produce phosphoric fertilizer and

elemental phosphorus. Acid is produced primarily in Pocatello or Conda, Idaho; elemental phosphorus is produced primarily in Soda Springs and Pocatello, Idaho, and Silverbow, Mont. Figure 3 shows the disposition of Idaho phosphate rock.

Deposits in Utah and Wyoming produce, or would produce, rock used for manufacturing acid and phosphorus. The Vernal Mine in Utah ships most of its phosphate rock out of the State for processing. It was assumed for the purposes of this study that if processing plants were not built on site or nearby, the acid-grade rock from the nonproducing deposits in Utah and Wyoming could be processed in Pocatello, Idaho; and furnace-grade rock for elemental phosphorus production in Soda Springs, Idaho. Approximately 80 pct of all western rock is consumed domestically, mainly in the Western States (13).

EVALUATION METHODOLOGY

For this study, 130 domestic mines and deposits were examined. These deposits include resources of phosphate rock at the demonstrated level that met the criteria of this study (listed below) and could be mined and beneficiated with current technology. The reserve and resource tonnage and grade calculations included in this study were derived from company data, published and unpublished sources, contractor-supplied information, and Bureau of Mines estimates.

Typically, beneficiated phosphate rock contains 7 to 20 pct moisture. Currently, most processes to convert

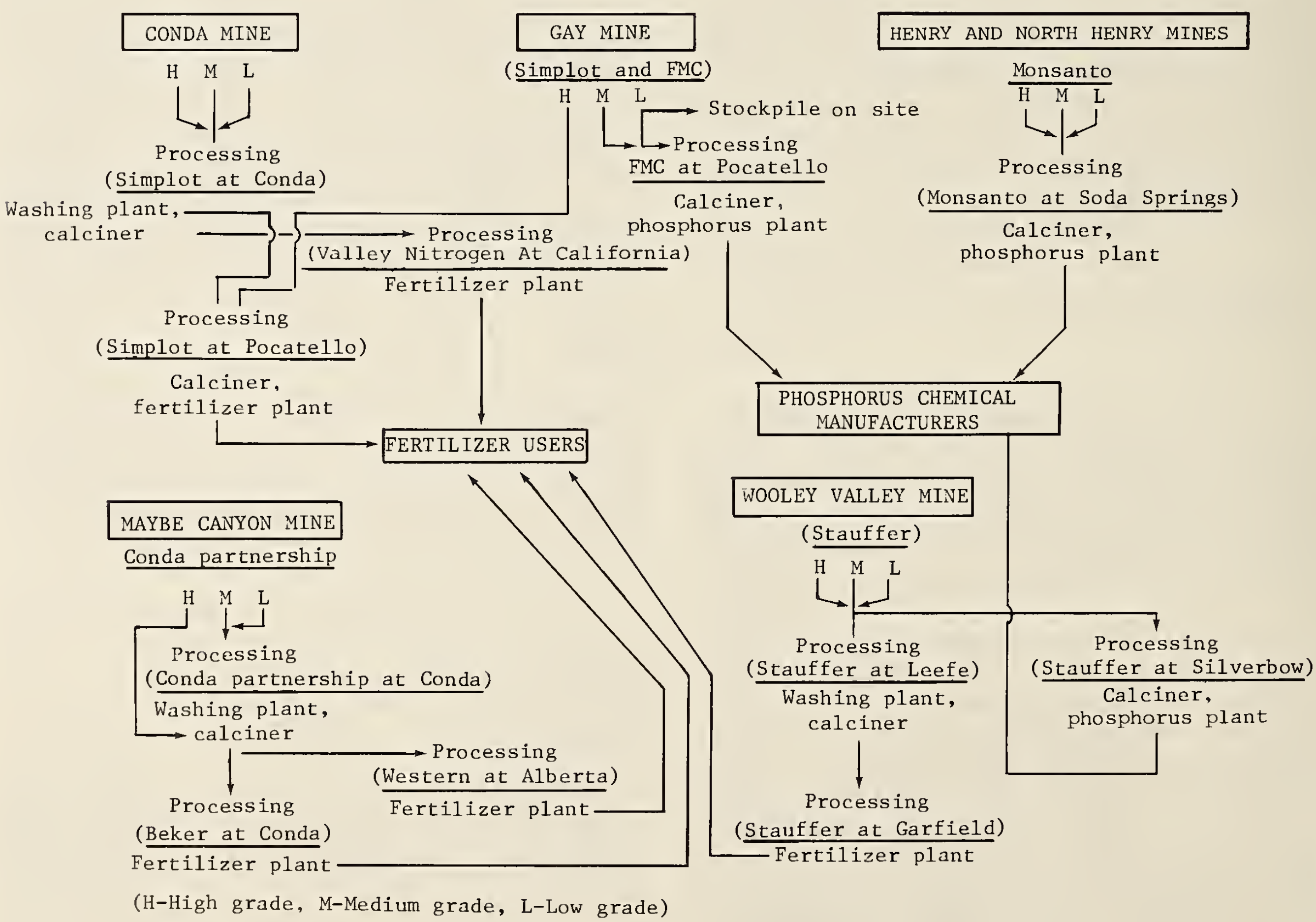

FIGURE 3. - Integration of Idaho phosphate deposits.

phosphate rock into its numerous end uses will accept wet rock feed, although less than 3 pct moisture is desirable. The final product in this study is dry phosphate rock sold f.o.b. mill. In this form, phosphate rock is used in chemical processes that create a number of products. The f.o.b. mill value was the common basis that was acceptable for this study; therefore the additional costs for further processing the phosphate rock into its many end products were not included. Transportation charges, although discussed in the report, are not included in the economic evaluations of individual phosphate properties. For this study, the term "phosphate rock" refers to the beneficiated product, and "phosphate ore" refers to the minable material in the ground. Reserves and resources expressed in terms of phosphate ore or rock are stated in dry tons.

The analysis methodology of this study follows:

1. The quantity and grade of domestic phosphate ore resources were evaluated in relation to physical and technological conditions that affected production from each deposit as of the study date, January 1981.

2. The capital investments and operating costs for appropriate mining, concentrating, and processing methods were estimated for each mine or deposit in January 1981 dollars.

3. An analysis of each operation determined the total tonnage of phosphate rock at its associated production cost that could potentially be recovered at specific production levels for each deposit.

4. After completion of the individual property analyses, all properties included in the study were simultaneously analyzed and aggregated into phosphate rock availability curves. These curves illustrate each operation's potential phosphate rock production at its average total cost of production. The average total cost of production for each operation represents its "incentive price" to produce phosphate rock: the price at which a firm would be willing to produce phosphate rock over the long run, where revenues are sufficient to cover the average total cost of production, including a return on investment high enough to attract new capital (1). The rate of return used in this study is a 15-pct discounted-cash-flow rate of return (DCFROR) on the total investments of each operation.

The data collected for this report are stored, retrieved, and analyzed in a computerized component of the Bureau's Minerals Availability System (MAS). After a deposit was selected for analysis, an evaluation of the operation was begun. The flow of the MAS evaluation process from deposit identification to development of availability information is illustrated in figure 4.

Information on the individual phosphate mines and deposits included in this study is in appendix A. Selection of deposits was limited to known deposits that have significant demonstrated reserves or resources. Reserves are material that can be mined, processed, and marketed at a profit under prevailing economic and technologic conditions. Resources are concentrations of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form that economic extraction of a commodity is currently or potentially feasible (19).

For the deposits analyzed, tonnage estimates were made at the demonstrated resource level based on the mineral resource-reserve classification system developed jointly by the Bureau of Mines and the U.S. Geological Survey (19). The demonstrated resource category includes measured plus indicated tonnages (fig. 5).

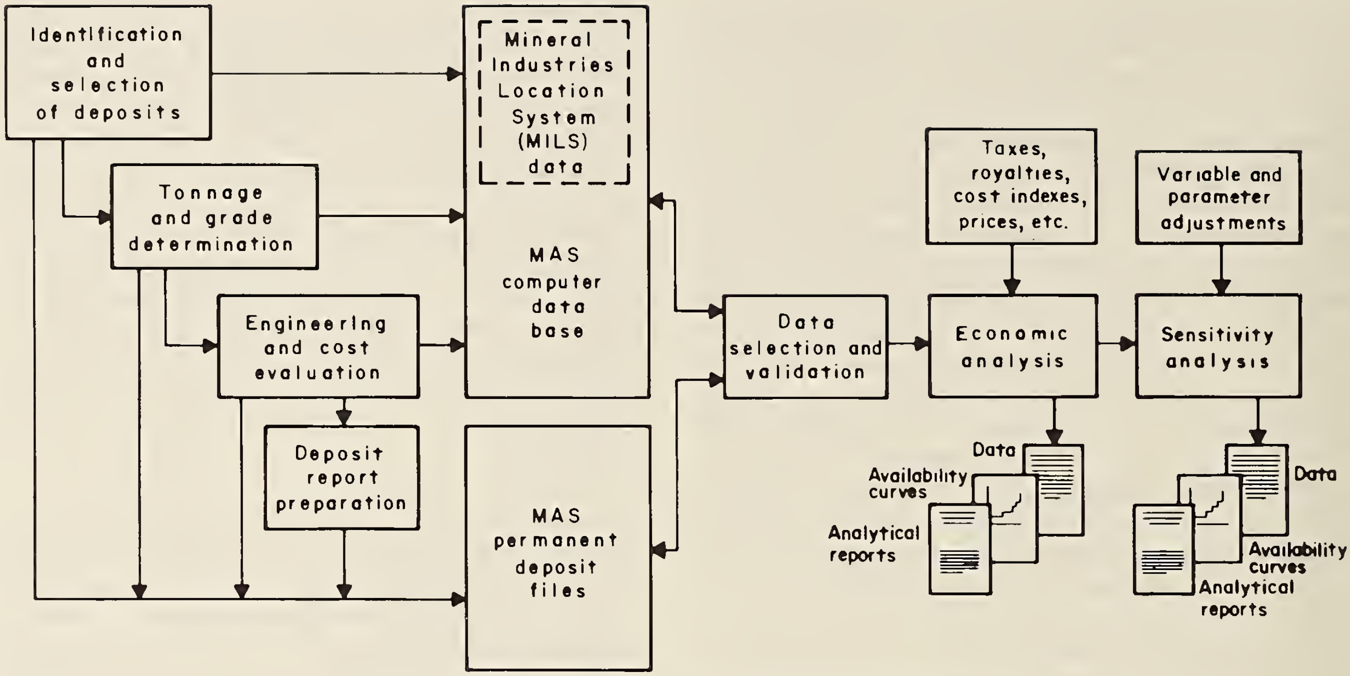

FIGURE 4. - Flow chart of MAS evaluation procedure.

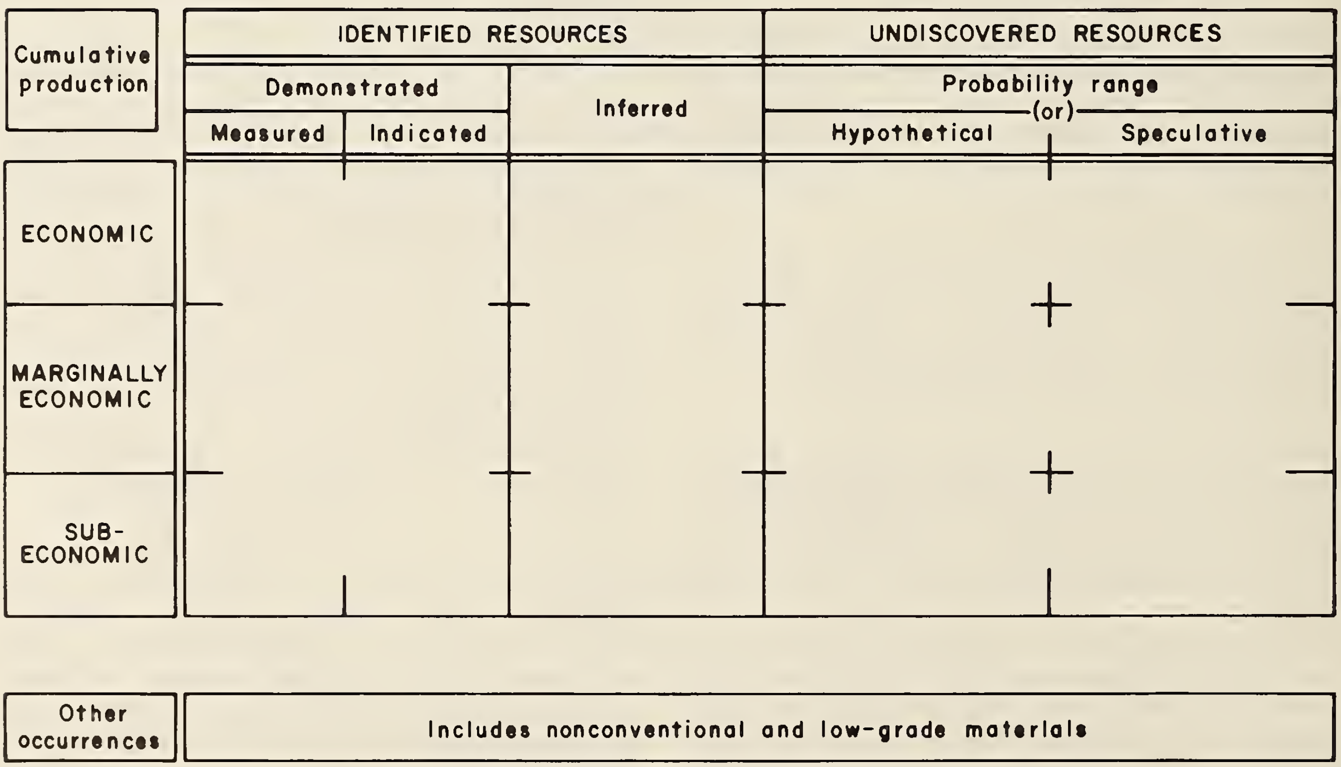

FIGURE 5. - Mineral resource classification categories.

To be included in the analysis, phosphate deposits had to meet technological criteria representing current acceptable industry standards. The criteria shown below for the southeastern deposits should be viewed as "guidelines" rather than an absolute lower limit (20):

1. Deposit size must be more than 5 million tons of recoverable phosphate rock,[6] and that tonnage must be within an average radius of 1.5 miles[7] from the center of the ore body.

2. Deposit size must be more than 10 million tons if the average overburden thickness is more than 6 m, and that tonnage must be within an average radius of 2 miles of the center of the ore body.[8]

3. Deposit size must be greater than 15 million tons if the overburden average thickness is more than 9 m, and that tonnage must be within an average radius of 2.5 miles from the center of the ore body.[9]

4. The flotation feed grade must be more than 4.6 pct P_2O_5.

5. The concentrate grade must be more than 27.5 pct P_2O_5.

6. The phosphate concentration must be 1 ton of recoverable product per 8 cu m of ore.

7. The ore zone must be more than 1.5 m thick.

8. Phosphate rock product must contain less than 1.5 pct magnesium oxide (MgO). (Resources of high-MgO phosphate deposits were quantified in this report, and technological developments are discussed, but deposits containing greater than 1.0 pct MgO are not evaluated in this study.)

The following criteria for developing resource estimates of Tennessee phosphate represent a range the central Tennessee phosphate companies recognize as representing acceptable minable deposits (22):

1. A minimum cutoff grade range of 16 to 17.2 pct P_2O_5.

2. Minimum ore thickness range of 0.6 to 1.2 m.

3. Maximum overburden-to-ore ratio range of 3:1 to 4:1.

4. A minimum ore body size of 22,675 dry tons of phosphate rock. The average ore body is small (150,000 to 1.2 million tons), which means that deposits at a number of separate locations may have to be mined to satisfy one company's annual requirement.

The study criteria for explored deposits in Utah and Wyoming include a minimum ore thickness of 0.91 m and a minimum average grade of 18 pct P_2O_5. For economic classification, minable resources were further subdivided by depth, thickness, dip, grade, and probability of occurrence. Resources above adit entry level[10] were estimated and economically evaluated after site-specific corrections were applied. The quantity of resources occurring below adit entry level was not costed or economically evaluated in this study because of their extremely high recovery cost.

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[6]Exceptions--if the deposit is adjacent to larger identified deposits or is in hardrock areas.

[7]This radius equates to the resource ore body covering one-half of the area of the deposit, at an average of 2,500 tons per acre.

[8]See footnotes 6 and 7 for exceptions and definitions.

[9]See footnotes 6 and 7 for exceptions and definitions.

[10]Adit entry level is defined as the nearly horizontal access to the minable resource. The adit level also serves as a conduit for natural water drainage.

Evaluation of each phosphate property included determinations of phosphate resources, deposit development, technologies, and costs. Information on the average grades, ore tonnages, and different physical characteristics affecting production from domestic phosphate deposits was obtained from numerous sources, including Bureau of Mines and Geological Survey publications, professional journals, State and industry publications, annual reports, company 10K reports and prospectuses filed with the Securities and Exchange Commission, data made available to the Bureau of Mines by private companies or under contracts, and estimates made by Bureau of Mines personnel based on personal knowledge and judgments.

Capital expenditures were calculated for exploration, acquisition, development, mine plant and equipment, and constructing and equipping the mill plant. Capital expenditures for mining and processing facilities include the costs of mobile and stationary equipment, construction, engineering, facilities and utilities, and working capital. A broad category, facilities and utilities (infrastructure), includes the cost of access and haulage facilities, water facilities, power supply, and personnel accommodations. Working capital is a revolving cash fund required for such operating expenses as labor, supplies, taxes, and insurance.

Mine and mill operating costs were also calculated for each deposit. The total operating cost is a combination of direct and indirect costs. Direct operating costs include materials, utilities, production and maintenance labor, and payroll overhead. Indirect operating costs include technical support and clerical labor, administrative costs, facilities, maintenance and supplies, and research. Other costs in the analysis are fixed charges including local taxes, insurance, depreciation, deferred expenses, interest payments (if applicable), and return on investment.

The Bureau of Mines has developed the Supply Analysis Model (SAM) to perform DCFROR analyses to determine the price of the primary commodity required for an operation to obtain a specified rate of return on all of its investments (6). This determined value for the phosphate rock price is equivalent to the average total cost of production for the operation over its producing life under the set of assumptions and conditions (e.g., mine plan, full-capacity production, and a market for all output) that are necessary in order to make an evaluation. The DCFROR is most commonly defined as the rate of return that makes the present worth of cash flow from an investment equal the present worth of all after-tax investments (12, p. 232). For this study, a 15-pct DCFROR was considered the necessary rate of return to cover the opportunity cost of capital plus risk.

Based on the MAS methodology, all capital investments incurred 15 years before the initial year of the analyses (January 1981) are treated as sunk costs. Capital investments incurred less than 15 years before January 1981 have the undepreciated balances carried forward to January 1981, with all subsequent investments reported in constant January 1981 dollar terms. This computation means that for producing operations, the undepreciated capital investment remaining in 1981 was calculated. All reinvestment, operating, and transportation costs are expressed in January 1981 dollars. No escalation of either costs or prices was included because it was assumed that any increase in costs would be offset by an increase in prices.

A separate tax-records file, maintained for each State, contains the relevant fiscal parameters under which the mining firm would operate. This file includes corporate income taxes, property taxes, and any royalties, severance taxes, or other taxes that pertain to phosphate rock production. These tax parameters are applied to each mineral deposit under evaluation, with the implicit assumption

that each deposit represents a separate corporate entity. The system also contains an additional file of economic indexes to allow for continuous updating of all cost estimates to the base date of the study.

Beginning with 1981, the first year of the analysis, detailed cash-flow analyses were generated for each preproduction and production year of an operation. Upon completion of the individual property analyses, all properties included in the study were simultaneously analyzed and aggregated onto resource-availability curves. The total resource-availability curve is a tonnage-cost relationship that shows the total quantity of recoverable product potentially available at each operation's average total cost of production over the life of the mine, determined at the stipulated (15-pct) DCFROR. Thus, the curve is an aggregation of the total potential phosphate rock that could be produced over the entire producing life of each operation, ordered from operations with the lowest average total cost of production to those with the highest. The curve provides a concise, easy-to-read, graphic analysis of the comparative costs associated with any given level of potential total output and provides an estimate of what the average long-run phosphate price (in January 1981 dollars) would likely have to be for a given tonnage to be potentially available. Three types of curves can be generated: (1) total-availability curves, (2) annual curves for selected years, and (3) annual curves at selected cost levels.

Certain assumptions are inherent in the curves. First, all deposits produce at full operating capacity throughout the productive life of the deposit, and this capacity remains constant unless planned expansions were known. Second, each operation is able to sell all of its output at a price equal to or greater than the average total production cost. Third, development of each nonproducing deposit began in the same base year (N). Since it is difficult, if not impossible, to predict when the explored deposits are going to be developed, this assumption was necessary. Also, the preproduction period allows for only the minimum engineering and construction period necessary to initiate production under the proposed development plan. Consequently, the additional time lags and potential costs involved in filing environmental impact statements, receiving required permits, financing, etc., have not been included in the individual deposit analyses.

GEOLOGY OF DOMESTIC PHOSPHATE DEPOSITS

THE SOUTHEAST

Phosphate deposits in Florida and North Carolina are part of a phosphate province that extends from southern Florida north into Virginia. Most phosphate was deposited in rocks of Middle Miocene age (the Hawthorn and equivalent formations). These rocks underlie much of peninsular Florida and the Atlantic coastal plain. During the Upper Miocene and into the Pliocene the phosphate of the Hawthorn Formation was reworked, concentrated, and enriched and redeposited in the Bone Valley Formation (of Upper Miocene to Pliocene age). Redeposition also occurred in channelike deposits of Pleistocene age. Phosphate in the Hawthorn and equivalent formations was deposited when cold, phosphorus-enriched marine water welled up onto a shallow warm-water plateau or when cold, along-shore currents were turbulently mixed with warmer waters, and phosphorus was precipitated. Structural features in the coastal plain partially controlled the deposition. The deposits are located in basins on the flanks of anticlines which were rising at that time; deposition occurred mainly in these basins. In central and southern Florida the Ocala Uplift and the Hillsborough High were the controlling features depositing phosphate on their flanks, whereas in northern Florida the Ocala Uplift was the main factor. In North Carolina, the Albemarle Embayment and an unnamed high were responsible (4).

Phosphate deposits in the Bone Valley Formation are composed of phosphate particles (ranging from pebble to clay size), quartz grains, carbonate grains, and clay minerals. The phosphate mineral is a carbonate-fluorpatite. Fine sand, sand, and pebble-size material can be recovered; silt and clay-size particles are too fine to recover economically with current technology. The amount of pebble (+1 mm size) in Bone Valley Formation deposits is important because most of the pebble is an economic product after simple screening. Therefore, the higher the pebble content of the phosphate ore, the less beneficiation is required on the remainder, resulting in lower overall operating costs.

The principal phosphate districts in the Southeast (fig. 6) are the Central Land-Pebble District of Florida (which includes the "southern extension"), the North Florida District (which extends into Georgia), and the Pungo River Phosphorite District of North Carolina. The Ridgeland Basin phosphorites in South Carolina (which includes the Savannah River deposits of Georgia) were not evaluated for this study since they currently are defined at the identified resource level only. Because of their proximity, Florida's east coast deposits are discussed along with the deposits in northern Florida. The Florida Hardrock District is currently of minor importance because no active mining has occurred since 1966 other than reworking phosphatic clay wastes from prior mining operations (7). A summary of the physical characteristics of these districts is shown in table 2.

The Central Land-Pebble District, the most important district in all the Southeast, has been the largest source of phosphate in the world for many years. It includes Polk and Hillsborough counties, where 18 producing mines and 13 nonproducing deposits were evaluated. In recent years there has been much activity towards extending this district south (the southern extension) to include phosphate resources in DeSoto, Hardee, Manatee, and Sarasota counties. Of the 27 deposits in the southern extension evaluated in this study, only 1 is currently producing (although another is developing). Only the portions of the deposits considered minable with current technology were evaluated, although the other resources not considered recovereable with current technology (particularly high MgO resources) were quantified.

In the Central Land-Pebble District, the Bone Valley Formation of Upper Miocene age and the leached surficial part of the Hawthorn Formation are mined. The Bone Valley Formation changes facies to the south and contains little or no phosphate in the southern extension, and only the upper clastic unit of the Hawthorn Formation is minable in that area.

TABLE 2. - Deposit characteristics of Southeastern U.S. phosphate districts (20)

	Central Florida Land-Pebble	Southern Florida Extension	Florida Hardrock	North Florida-Georgia	East Florida Coast	Pungo River Phosphorite, North Carolina
Overburden thickness...m..	6-9	6-12	3-8	6-15	15-46	27-40
Ore zone thickness...m..	5-8	5-11	2-9	3-8	2-15	12-15
Pebble product pct..	20-60	10-25	60-100	10-20	0	NA
P_2O_5 product pct..	31-33	30-31	30-35	30-33	28-30	30-31
MgO product pct..	0.5	0.8	NA	0.75	0.9-2.0	0.5

NA Not available.

FIGURE 6. - Southeastern U.S. phosphate districts. (Modified from reference 4.)

The deposits in the Central Land-Pebble District have ore zones ranging from 5 to 8 m thick, with an overburden of 6 to 9 m. In the southern extension deposits, the ore zones are 5 to 11 m thick, and the overburden is 6 to 12 m thick. In both the central and southern extension areas, the overburden-to-ore ratio is less than 2:1. Farther south, the overburden and ore zones become progressively thicker until at some point the total depth is too great for mining by current technology.

The percentage of pebble in product for Central Land-Pebble District deposits is 20 to 60 pct, whereas the deposits in the southern extension average considerably less (10 to 25 pct), and the pebble fraction in the southern deposits contains high amounts of calcite and dolomite (the magnesium-bearing mineral). The average P_2O_5 content of the product is 31 to 33 pct in the Central District but 30 to 31 pct in the south. The iron-aluminum oxide percentage in the product in both areas is within acceptable limits (less than 3.5 pct).

The hardrock deposits of Florida lie along the east limb of the Ocala Uplift or Arch. Although they had been producing since about 1900, there has been no significant mining activity since the mid-1960's. The irregularly sized deposits occur as small pods in this northwest-southeast-trending district. The deposits are complex in origin. They were derived from the Hawthorn Formation and are in rocks of post-Hawthorn age in the so-called Alachua Formation, which includes rocks of Upper Miocene, Pliocene, Pleistocene, and Holocene age. Ore thickness in the deposits ranges from 2 to 9 m; overburden ranges from 3 to 8 m (approximately a 1:1 overburden-to-ore ratio). The percentage of coarse rock (pebble, lump rock, plate rock, etc.) in the ore is very high, ranging from 60 to 100 pct; the P_2O_5 content of the product is also high, ranging from 33 to 35 pct. Although the percentage of magnesium oxide is minor, the iron and aluminum content can be considerable. The Hardrock District includes deposits in Citrus, Lafayette, and Marion Counties. This evaluation included five deposits, one of which is presently processing phosphatic clay wastes from prior mining operations (7).

The North Florida deposits occur in Alachua, Bradford, Baker, Clay, Columbia, and Hamilton Counties. This evaluation includes eight deposits from four of these counties; the only two producing mines are in Hamilton County. The east coast deposits (of which only one, in Brevard County, was evaluated) are included here for discussion purposes. The North Florida deposits are in the Hawthorn Formation and an unnamed upper Miocene formation equivalent in age to the Bone Valley Formation. The minable portion includes the upper part of the Hawthorn Formation and the Upper Miocene strata. Ore thickness ranges from 3 to 8 m (2 to 15 m on the east coast), and overburden from 6 to 15 m (15 to 46 m on the east coast); thus the overburden-to-ore ratio is 2:1 in the north and 3:1 in the east. The pebble fraction of the product ranges from 10 to 20 pct in the north, but is almost nil on the east coast. The P_2O_5 content of the product averages 30 pct; the northern deposits may be as high as 33 pct and the eastern deposits as low as 28 pct. The percent magnesium oxide in the product is within the acceptable limit of less than 1 pct for the northern deposits, although some of the material on the east coast is very high in magnesium oxide, reflecting a somewhat higher content of dolomite. The east coast material would be difficult to beneficiate under present technological constraints.

Two deposits in North Carolina were evaluated: Lee Creek is a producer, and the North Carolina Phosphate Deposit is under development. Both deposits are in Beaufort County within the Pungo River Phosphorite District and occur in the Middle Miocene Pungo River Formation, equivalent in age to the Hawthorn Formation of Florida. The ore zone ranges from 12 to 15 m thick with 27 to 40 m of

overburden (overburden-to-ore ratio is more than 2:1). The small percentage of pebble is rejected from the product because of contamination from shell material and dolomite. The product, nearly all derived from phosphatic sands, has a grade of approximately 30 pct P_2O_5. The iron and aluminum oxide content is approximately 2 pct, and the magnesium oxide content is approximately 0.5 pct, both well within acceptable limits.

TENNESSEE

Phosphate has been produced from deposits in Tennessee since 1900, although most deposits are nearly mined out. The three types of phosphate deposits in the State are the so-called brown rock, blue rock, and white rock. The only deposits considered for this study are the brown-rock type (the other types being insignificant or uneconomic); these occur mainly as "blanket deposits" derived from phosphatic limestones of Ordovician age. The deposits are residual, formed in the modern weathering cycle by acid leaching of the marine phosphatic limestones. The phosphate mineral in these deposits, a carbonate fluorapatite, occurs as sand-sized grains intermixed with clays (called muck) or as higher grade plates (called lump rock) (22). Overburden for these deposits averages 4 m in thickness, and the ore zones average 2 m in thickness, (a 2:1 overburden-to-ore ratio). The phosphate ore grade ranges from 17 to 23 pct P_2O_5, whereas the beneficiated rock product grade ranges from 26 to 29 pct P_2O_5. All the deposits studied are centered around Maury County in the central portion of the State (fig. 7) (22).

Most of the mines in Tennessee are very small, ranging from 150,000 to 1.2 million tons of production per year. Many separate deposits are mined concurrently to fulfill a company's production requirements. For this study, many of these deposits have been grouped, by company, into individual evaluations.

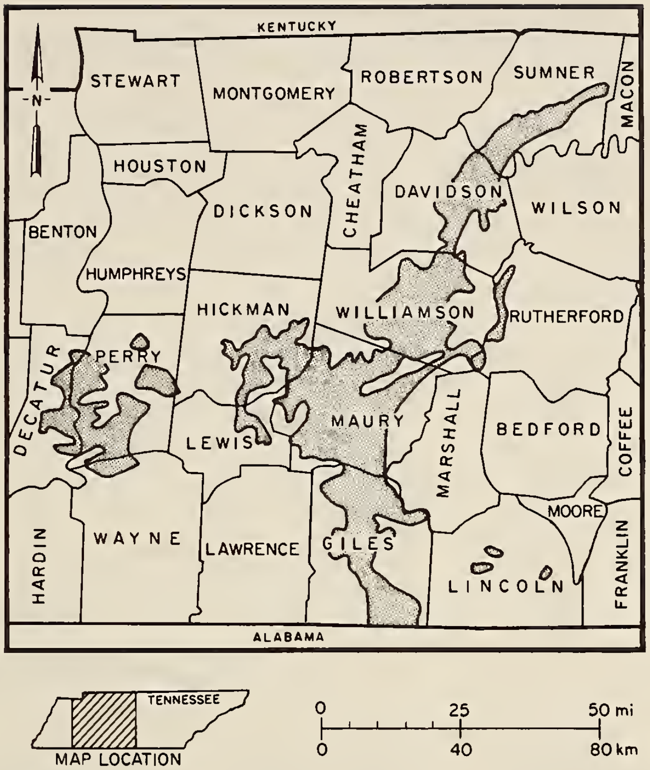

FIGURE 7. - Location of Tennessee phosphate deposits.

THE WEST

The phosphate deposits of the Western United States are located in Idaho, Montana, Utah, and Wyoming, with most of the present mining activity occurring in Idaho (fig. 8) (10). The western deposits occur in the Permian Phosphoria Formation, with the phosphate rock composed primarily of carbonate fluorapatite pellets but also occurring in oolitic, pisolitic, nodular, and bioclastic forms.

These deposits were apparently formed by cold, phosphorus-rich marine water upwelling into a large trough-platform environment adjacent to a continental margin. Phosphate-rich beds appear to reach their maximum thickness at the trough-platform boundary.

The Phosphoria Formation consists of phosphorite, chert, limestone, mudstone, shale, and siltstone. Phosphate is mined

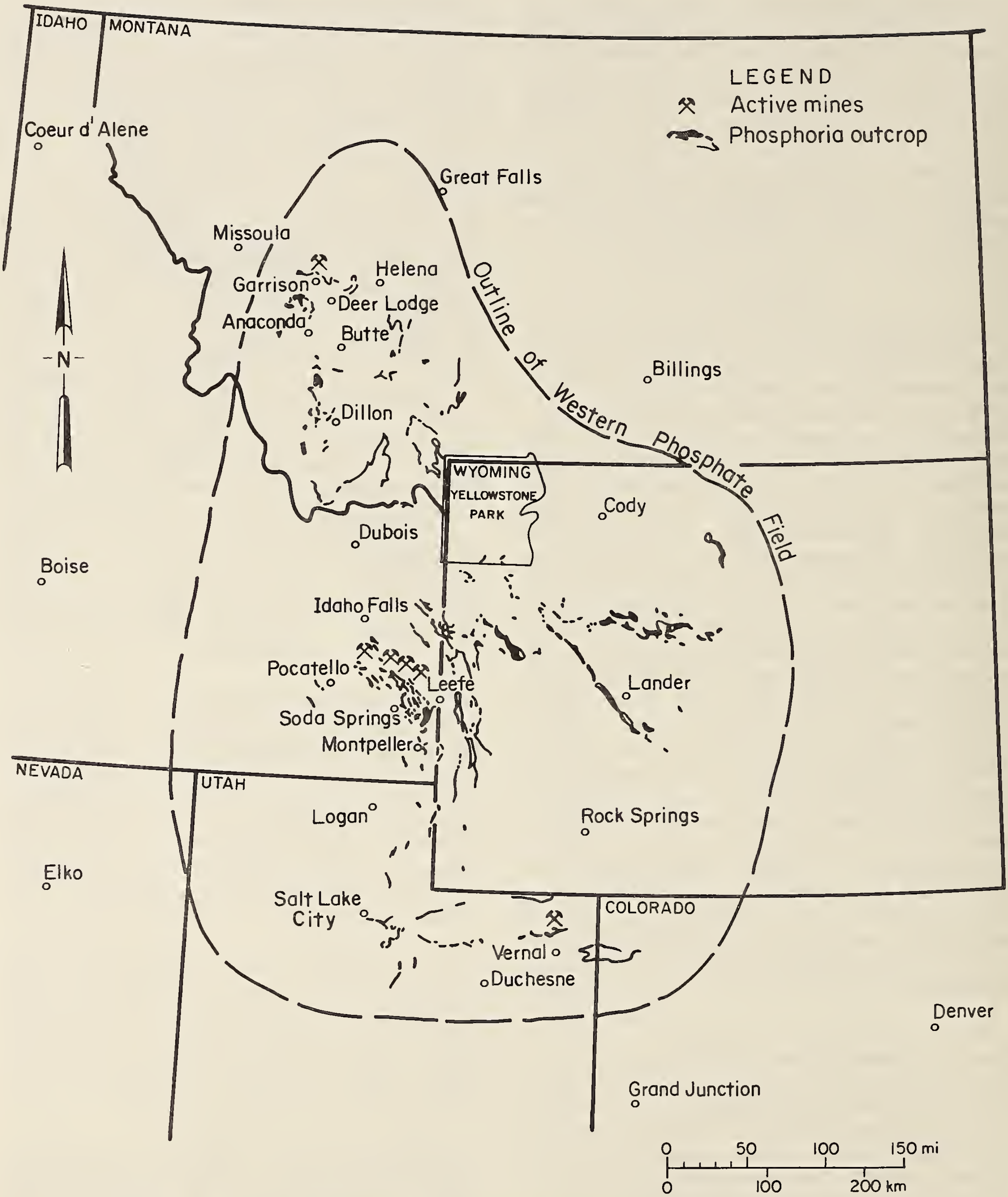

FIGURE 8. - Location of Western U.S. phosphate deposits. (Modified from reference 10.)

principally from the Mead Peak Member, primarily from its upper and lower zones. These two ore zones range in thickness from 9 to 18 m, and the middle waste rocks (mainly mudstones and carbonates) are typically 30 m thick. Overburden at these deposits, averaging only 5 to 10 m, consists of loose, unconsolidated sediments. The upper phosphate zone tends to be high in phosphate content because of surface-rock weathering that leached out much of the carbonate. The zone averages 5 to 8 m in thickness, and phosphate content ranges from 20 to 24 pct P_2O_5. The lower zone is much thicker, ranging in thickness from 9 to 12 m; its phosphate content ranges from 20 to 30 pct P_2O_5, increasing in value in the lower portions of the zone.

The phosphate deposits of the Phosphoria Formation are altered at the surface. The altered rocks have been sufficiently weathered to remove much of the aluminum, calcium, iron, and magnesium, resulting in lower grades for the deleterious materials and higher P_2O_5 grades. These are the rocks that are currently being mined. The unaltered rocks have not been weathered and occur as much as 500 m below the surface (5). These rocks are not presently being mined because of their depth and because of the difficulty in processing them owing to the high amounts of impurities ($CaCO_3$, MgO, Fe, etc.) that they contain. For these reasons, the unaltered resources are not included in this study.

DOMESTIC PHOSPHATE RESOURCES

Of the 130 mines and deposits evaluated for this study, 71 are in Florida, 2 in North Carolina, 5 in Tennessee, 8 in Idaho, 1 in Montana, 17 in Utah, and 26 in Wyoming. Fifty-six pct of these deposits are in Florida and North Carolina and contain over 82 pct of the in situ ore and 60 pct of the recoverable phosphate rock from demonstrated resources in the United States. Total domestic resources of phosphate ore from all the deposits evaluated at the demonstrated level are 28.2 billion tons containing 6.4 billion tons of recoverable phosphate rock. Following is a discussion of domestic phosphate resources, by region.

THE SOUTHEAST

As of January 1981, at the demonstrated resource level, almost 4 billion tons of phosphate rock was potentially recoverable from the southeastern deposits evaluated (table 3). The deposits in the Central Land-Pebble District, where most mining occurs, account for less than 20 pct of this resource whereas the deposits in the southern extension contain almost 40 pct. Figure 9 shows the approximate coverage of deposits evaluated for this study in the Central Land-Pebble District, including the southern extension. The shaded area includes all the demonstrated resources considered minable. The remainder of the resources within the area were classified as inferred or hypothetical. Much of this material is presently considered to be unacceptably high in magnesium oxide or is considered unminable with present technology. As shown in table 4, there is an estimated 5.9 billion tons of recoverable phosphate rock in the Southeast at the inferred resource level and an additional 14.3 billion tons at the hypothetical level.

A major difference between the deposits in the Central Land-Pebble District and those in the southern extension is the amount of magnesium oxide in the product. During phosphoric acid production, the different carbonate minerals consume sulfuric acid; increased amounts of magnesium oxide in the phosphate rock feed increase this sulfuric acid consumption, and $MgSO_4$ does not precipitate as does $CaSO_4$. Higher magnesium oxide content also increases the viscosity of the acid and causes problems in producing diammonium phosphate. Florida phosphate rock has traditionally contained acceptable quantities of magnesium oxide; however, much of the phosphate resource potential from Florida (particularly the southern extension) occurs in deposits containing

TABLE 3. - Summary of Southeastern U.S. demonstrated phosphate resources

(Quantities in million metric tons; all grades weighted-average percent P_2O_5)

District and county	In situ ore tonnage	Extractable ore grade	Recoverable rock product	Rock product grade
Central Florida Land-Pebble District:				
Hillsborough	900	7.5	150	33.1
Polk	2,519	8.0	500	31.6
Total or weight-average	3,419	7.9	650	32.0
Southern Florida extension:				
Hardee	4,710	5.8	599	30.9
Manatee	6,383	4.7	692	30.4
Others[1]	1,175	4.9	145	30.2
Total or weight-average	12,268	5.2	1,436	30.6
Florida Hardrock District:				
All counties[2]	W	W	W	W
Northern and East-Coast Florida Districts:				
Columbia	1,478	4.5	148	30.0
Others[3]	2,635	5.4	323	30.0
Total or weight-average	4,113	5.1	471	30.0
Pungo River, N.C. District	W	W	W	W
Other	3,488	NAp	1,322	NAp
Grand total or weight-average	23,288	7.0	3,879	30.8

NA Not applicable since these deposits are in different districts of the southeast; therefore, weight average grades would not be relevant.

W Withheld to avoid disclosing individual company confidential data; included as other.

[1]Includes De Soto and Sarasota Counties.

[2]Includes Citrus, Lafayette, and Marion Counties.

[3]Includes Alachua, Bradford, Brevard, and Hamilton Counties.

TABLE 4. - Additional phosphate resources, Southeastern United States

(Million metric tons of recoverable phosphate rock)[1]

	Inferred[2]	Hypothetical[3]
Georgia	2,834	1,000
South Carolina	101	100
Florida	2,977	5,175
North Carolina	-	8,000
Total	5,912	14,275

[1]Does not include recently discovered resources offshore (Savannah River, Blake Plateau, and Onslow Bay), which may potentially contain many billions of tons of recoverable phosphate rock.

[2]Tonnages shown for Georgia, South Carolina, and North Carolina are derived from the Zellars-Williams report on these States (21). Florida resources are based on the inferred resource estimates directly from the individual deposits studied plus any additional high and low-MgO resources in deposits not included in the study.

[3]Based on communications with James Cathcart of the U.S. Geological Survey.

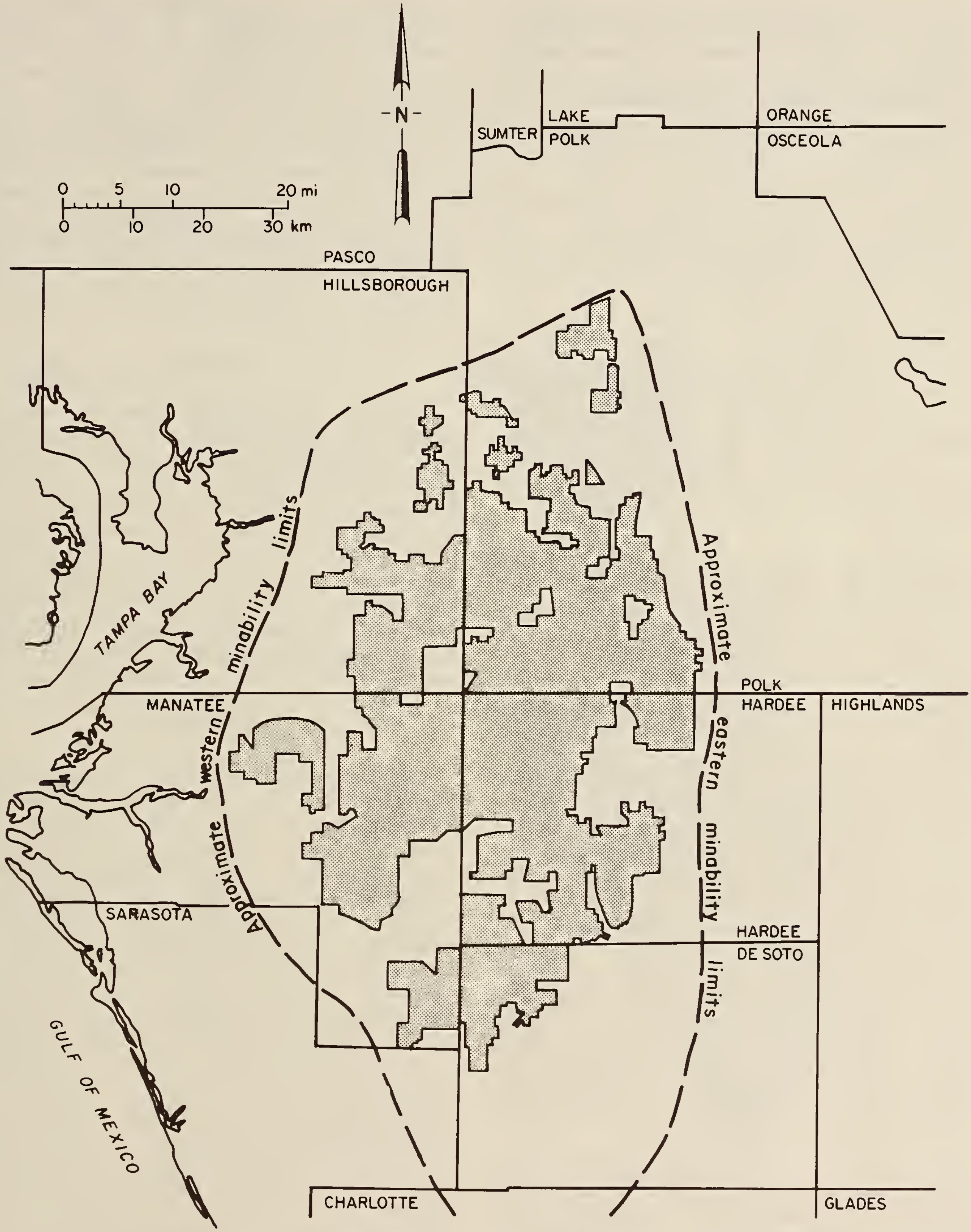

FIGURE 9. - Area coverage in the Central Land-Pebble District (including the southern extension), Florida. (Shaded area includes all demonstrated resources for this district considered for this evaluation.)

quantities of magnesium oxide that are currently considered unacceptable (more than 1.0 pct). Research is underway to solve this problem by developing methods for beneficiating high-magnesium phosphate to within acceptable limits (1.0 pct or lower). The Bureau of Mines research center in Tuscaloosa, Ala., is working on this problem and has recently published a report dealing with this issue (8). Numerous phosphate companies--including International Minerals and Chemical Corp. (IMC), W. R. Grace, Gardinier, and the TVA National Fertilizer Development Center--are also working to solve the magnesium oxide problem. Some of the processes being developed include the use of heavy-media separation techniques and improved flotation techniques to remove dolomite (which contains most of the magnesium oxide) from the phosphate ore.

Phosphate resources containing more than 1.0 pct magnesium oxide were not included (or costed) for the analysis. At the identified resource level, an estimated 2 billion tons or more of recoverable phosphate rock exists in high-magnesium-oxide deposits in Florida with most of the tonnage classified as inferred. This estimate is very conservative since most of these deposits have not been sufficiently drilled. High-magnesium-oxide resources are mainly in the counties of De Soto (approximately one-third of the total) and Hardee (approximately one-third), with the balance in Manatee and other counties. The development of new technologies for processing high-magnesium-oxide phosphate will significantly increase Florida phosphate reserves, although at an increased cost. It has been suggested that these new technologies would add between $3 and $6 per ton of product, although these figures are unconfirmed.

The future resource potential for Florida is almost entirely in the Hawthorn Formation (including the southern extension and high-magnesium-oxide deposits). Figure 10 is an isopach map showing the thickness of the overburden overlying the Hawthorn Formation. Figure 11 shows the thicknesses of the formation itself, including the location of test cuttings from well holes used to evaluate the location and thickness of the formation and overlying sediments. These maps give clear indication of the vast extent of the Hawthorn Formation and its thickness, and the tremendous amounts of phosphate in Florida, particularly in the southern part of the State. Although at present much of this material is considered technologically unminable or highly uneconomical to mine, this great resource potential does exist.

TENNESSEE

Like the rest of the domestic deposits evaluated, resources for Tennessee are at the demonstrated resource level and have been updated to January 1981. A total of 28.5 million tons of phosphate rock is potentially recoverable from a resource of 61.3 millin tons of phosphate ore, with most of this potential from producing mines. The individual ore bodies in Tennessee are well defined; any undiscovered deposits of brown rock in the region would most likely be quite small.

THE WEST

The values for proposed or developing deposits in Idaho are based on resource information in the recent Caribou National Forest Phosphate Environmental Impact Statement (18); Bureau personnel developed the resource values and evaluated the explored deposits in Utah and Wyoming. The demonstrated resources of the Western United States as of January 1981 are listed in table 5. There are approximately 4.9 billion tons of phosphate material in the western deposits evaluated for this study, containing about 2.5 billion tons of recoverable phosphated rock. In Idaho and Montana, where mining occurs in some of the higher grade rock, deposits contain just over 10 pct of all the potentially recoverable phosphate rock from the western area. Wyoming alone contains over half the potentially recoverable phosphate rock in the West.

TABLE 5. - Summary of Western U.S. demonstrated phosphate resources
(Quantities in million metric tons; all grades weighted-average percent P_2O_5)

State	In situ ore tonnage	In situ grade	Recoverable rock product	Rock product grade
Idaho and Montana[1]................	352	25.6	237	31.0
Utah.............................	1,882	20.1	930	27.9
Wyoming..........................	2,658	21.5	1,305	27.7
Total or weight-average.......	4,892	21.3	2,472	28.1

[1]Montana was included here to avoid disclosing individual company confidential data.

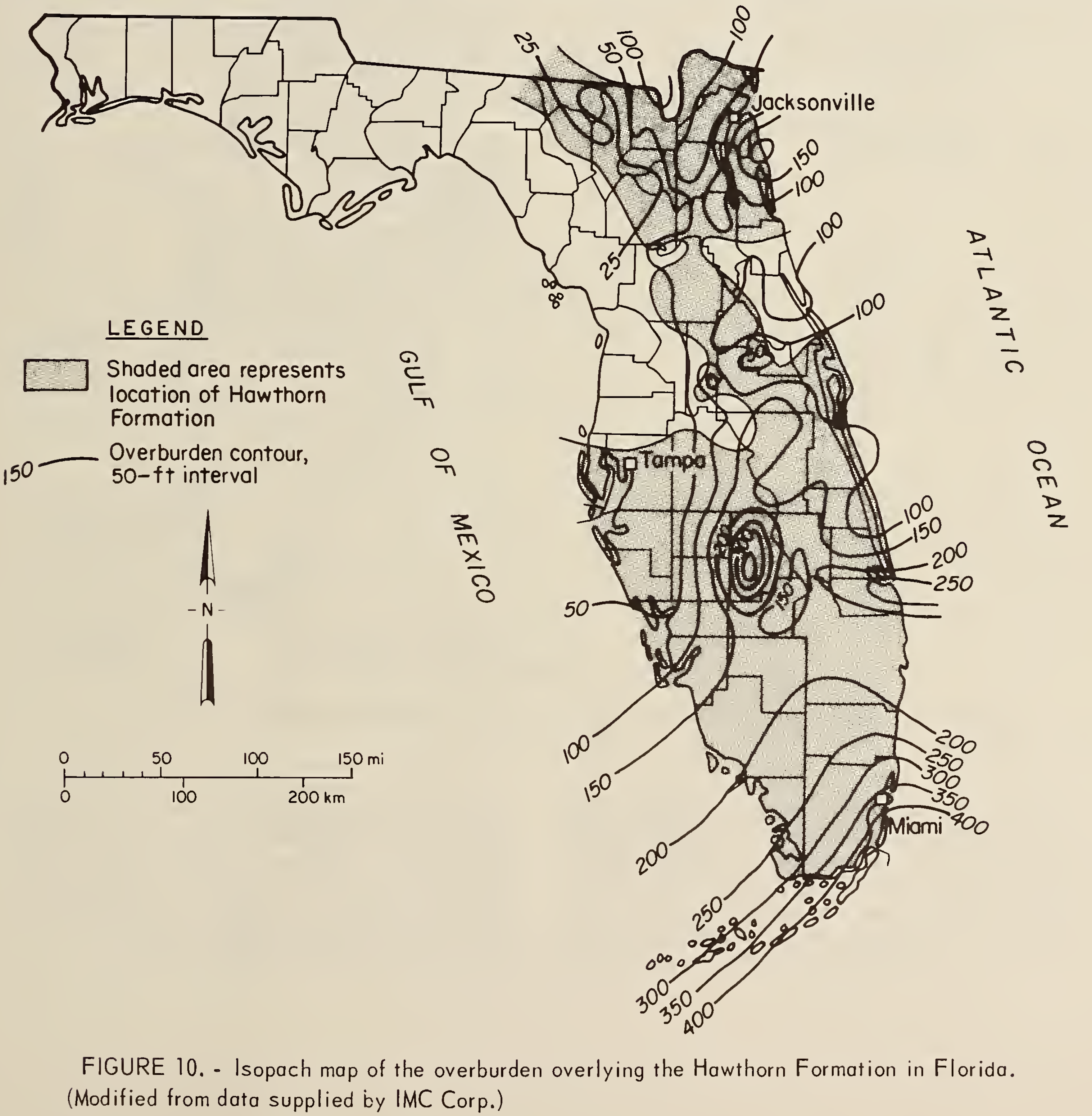

FIGURE 10. - Isopach map of the overburden overlying the Hawthorn Formation in Florida. (Modified from data supplied by IMC Corp.)

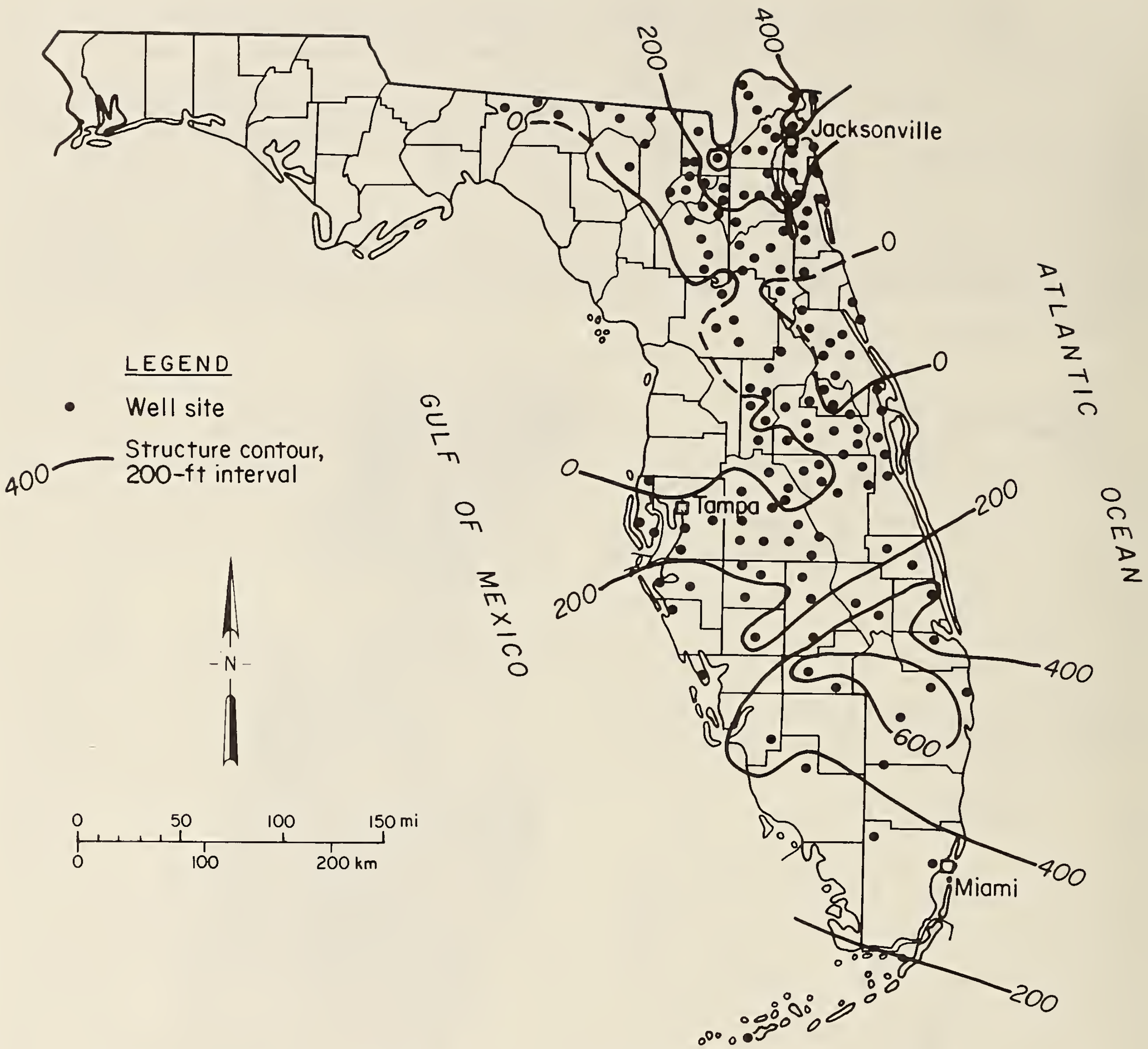

FIGURE 11. - Isopach map of the Hawthorn Formation in Florida. (Modified from data supplied by IMC Corp.)

Not costed for this study is more than 1 billion additional tons of recoverable phosphate rock in these four States at the inferred resource level (most of which is of the unaltered type). In addition to these inferred resources are an estimated 10 billion tons of recoverable rock above adit-entry level at the hypothetical resource level and below adit-entry level as much as 100 billion tons to a depth of 2,000 m and almost 300 billion more below 2,000 m (5).

DOMESTIC PHOSPHATE MINING AND BENEFICIATION METHODS

Strip mining is the most common method of mining phosphate ore in Florida. In this operation, a dragline digs a series of parallel cuts and casts the overburden into previously mined cuts. A dragline then mines the exposed ore (matrix) and transfers it to an aboveground slurry pit from which it is pumped to the washer plant. An estimated 85 pct of the ore is physically recovered from the cut.

In North Carolina and parts of Florida, dredges are used. In the Florida operation, a dredge excavates overburden and the spoil is pumped through pipelines to land reclamation areas behind the mining operation. Another dredge follows, and the exposed ore is removed and hydraulically transported through pipelines and booster pumps to the washer plant (mill). In North Carolina only the upper portion of overburden is removed by a dredge. The ore and lower portions of overburden are removed by draglines. In dredging operations, the mine recoveries generally range from 80 to 90 pct.

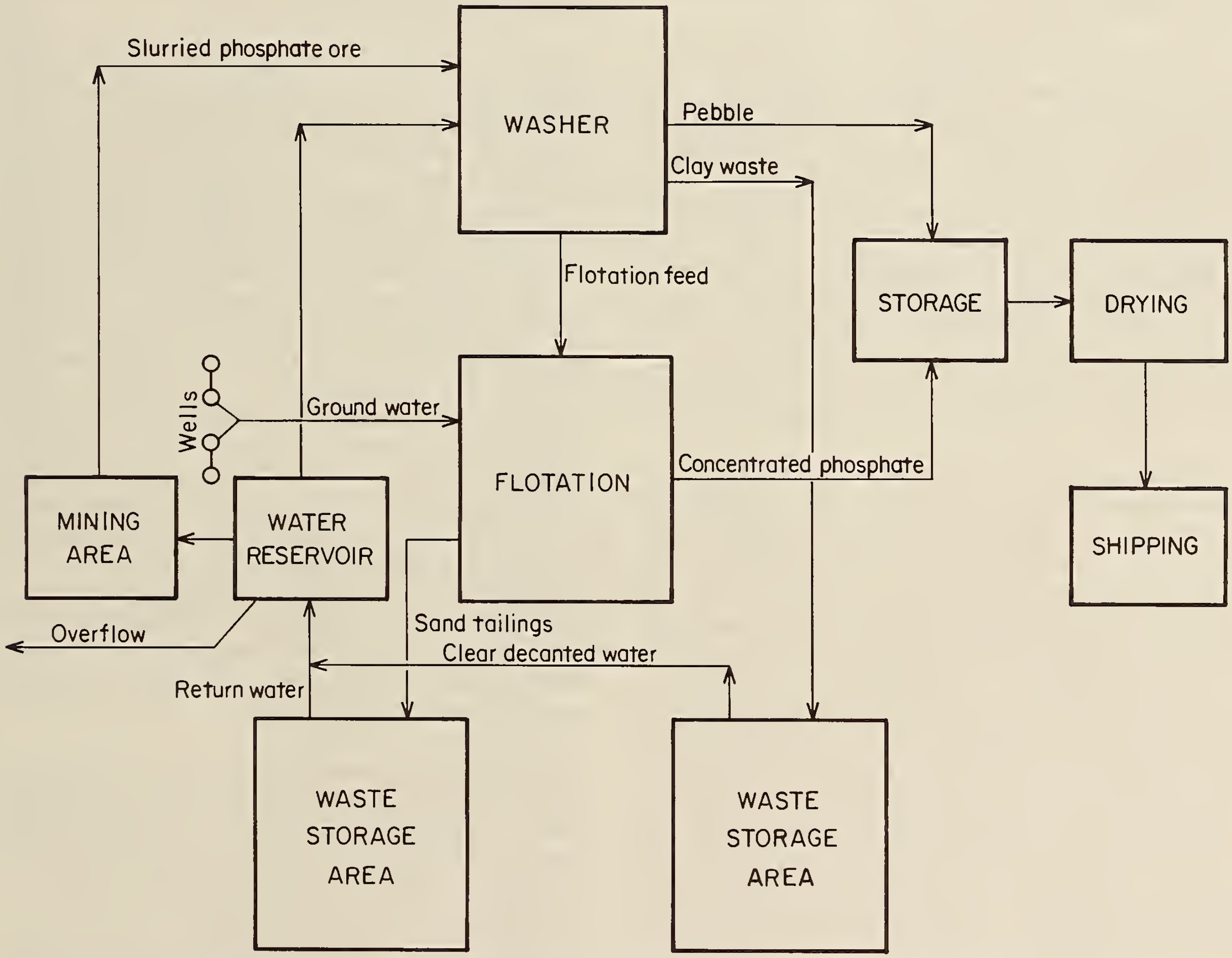

FIGURE 12. - Typical process flowsheet, Southeastern United States.

An average sized phosphate mine in the Southeast treats about 9 million tons of ore per year, producing approximately 2 million tons of phosphate rock. In the Southeast, phosphate ore is beneficiated through a series of washing, sizing, and flotation circuits which separate phosphate pellets from clay and quartz. The pebble portion of the ore is screened out during the washing stage. The processing stages of a typical southeastern phosphate beneficiation plant are shown in figure 12. Phosphate recovery from these plants is typically 80 to 90 pct. The product from a plant of this type is phosphate rock suitable for phosphoric acid production.

The Bureau of Mines, in conjunction with a Florida phosphate producer, is experimenting with the borehole mining method to recover the deep, untapped phosphate resources of Florida, particularly in the northeastern part of the State. In this method, the deep phosphate ore is mined through a borehole using a water-jet cutting system in which the ore is slurried and pumped to the surface. This method, although still in the research stage, could make available additional resources of phosphate rock.

Tennessee phosphate ore is also mined with draglines, although the draglines used are much smaller than those used Florida. Draglines used in Tennessee must be small enough to remove the ore from narrow crevices and mobile enough to be moved easily and quickly from one mine site to another. In a typical operation, a bulldozer clears topsoil and removes the clay overburden. A dragline then removes the ore from a pit, typically attaining an 80-pct mining recovery; a bulldozer then backfills mined-out areas with spoil. The ore is transported by truck, or rail for longer hauls, to a field washer or a washer at the chemical plant.

The basic beneficiation process includes only a washer plant, which typically recovers 60 to 75 pct of the phosphate rock. The ore is slurried and then passes through a series of washers, scrubbers, screens, and cyclones to produce a silt and sand-sized rock product. Nearly all the phosphate rock product from the washer plants is used as electric furnace feed for production of elemental phosphorus, which is used in the chemical industry.

The average phosphate operation in Tennessee (which includes production from a number of individual mines) has a capacity of approximately 1 million tons of ore treated per year, yielding 600,000 tons of phosphate rock.

Open pit mining methods predominate in the Western U.S. phosphate mines, although there is one underground operation (Cominco American's Warm Springs mine at Garrison, Mont.). There are four producing open pit mines in Idaho and one in Utah. In the open pit operations, topsoil, if present, is removed and stockpiled for later reclamation. Cherty overburden is drilled, blasted, and loaded by electric shovels into haulage trucks for placement into mined-out pits or on dumps. Waste shales, when stockpiled, are ripped or lightly blasted, then stripped by scrapers and push-dozers, with most of the waste going to stockpiles. The ore is mined by hydraulic shovels and hauled by trucks to a stockpile area for eventual beneficiation. At the underground mine in Garrison, Mont., ore is extracted by a modified room-and-pillar method with overhand open stopes.

The average phosphate mine in the West treats around 1.3 million tons of ore per year. The average amount of product recovered from a mine this size is just under 900,000 tons of phosphate rock.

Most Western U.S. phosphate ore is beneficiated by crushing, washing, classifying, and then drying (fig. 13), with a typical recovery of 65 to 85 pct;

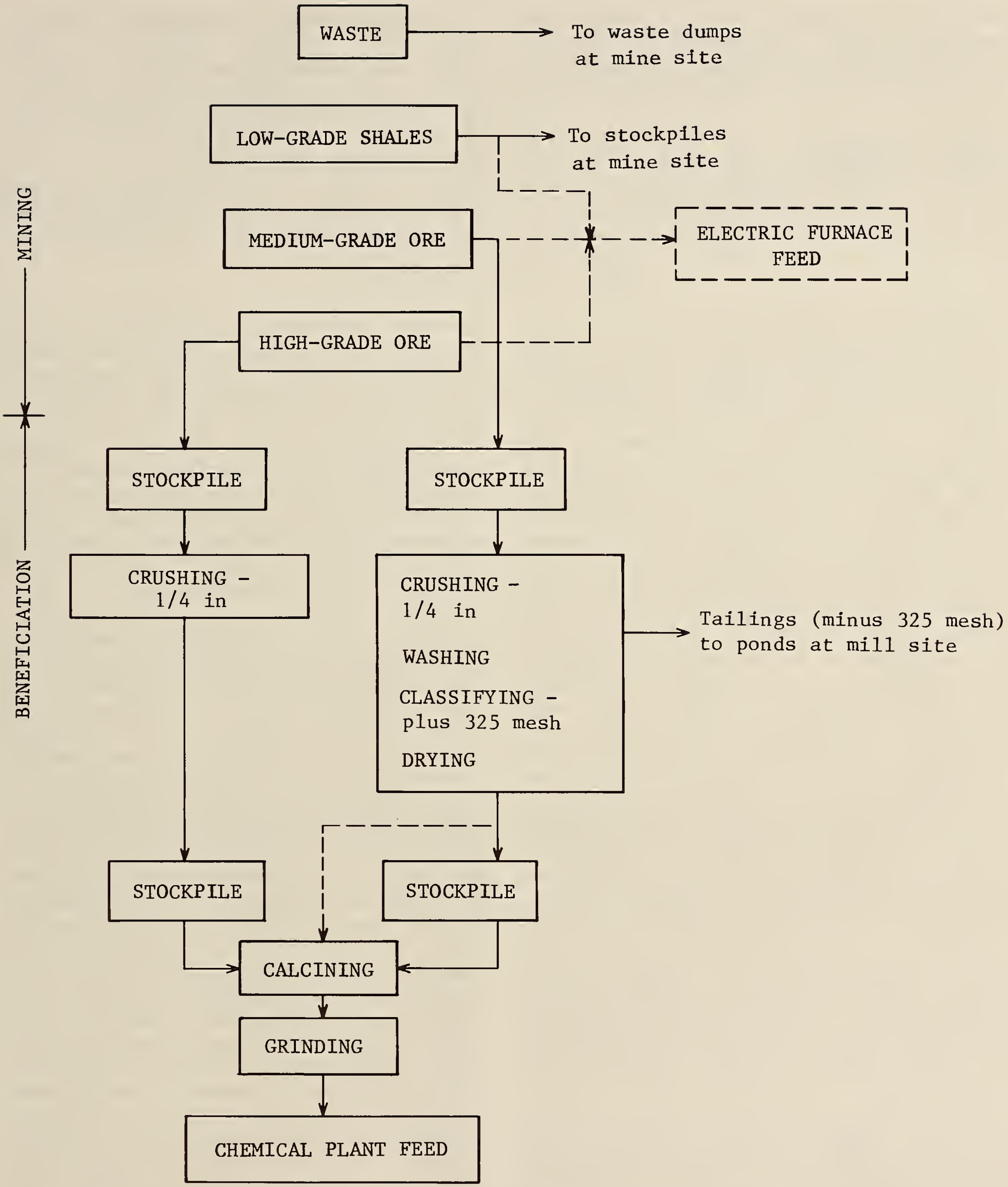

FIGURE 13. - Typical process flowsheet, Western United States.

however, the Vernal Mine in Utah also uses flotation. The product is typically calcined to remove carbonaceous materials and then sent to a chemical plant.

The four grade classifications for western phosphate rock are acid or fertilizer grade (+31 pct P_2O_5), also termed high grade; furnace grade (24 to 31 pct P_2O_5); beneficiation grade (18 to 24 pct P_2O_5), also termed medium grade; and low-grade shale (10 to 18 pct P_2O_5). Acid-grade rock is used as direct chemical plant feed; furnace-grade rock is used for electric furnace feed; beneficiation-grade rock is upgraded to either furnace or acid grade (most frequently to furnace grade) through the beneficiation stages shown on figure 13; and low-grade shales are stockpiled for possible future use.

DOMESTIC PHOSPHATE COSTS

Phosphate deposits in the Western United States were costed using various cost methodologies such as scaling techniques (from both current operations or models); the MAS Cost Estimating System (CES), a computerized version of the Bureau of Mines capital and operating cost manual (15); and actual reported company costs. Costs for producing mines and nonproducing deposits in Florida, North Carolina, and Tennessee are from cost models which Zellars-Williams, Inc., developed under contract (20). The cost models are calibrated by confidential cost information from companies active in the phosphate industry. To protect the confidentiality of the cost data obtained, contributing operations were grouped into different cases according to size, age, reserve characteristics, and production cost criteria. A production cost for a "typical" mine representative of each case was calculated by averaging actual or estimated costs for the mines so grouped. These cost models were updated and modified by Bureau of Mines personnel for site-specific situations, such as matrix X, the number of draglines, pebble content, etc. The six cost models Zellars-Williams, Inc., developed for Florida, with costs updated to January 1981 dollars, are presented in appendix B.

Table 6 illustrates the average operating costs used to develop the phosphate availability curves for U.S. phosphate mines and deposits. Mine and mill operating costs in Florida are most affected by electrical power costs for the draglines and washer-flotation plants, labor, supplies, reagents, and drying oil. In the West, the greatest portion of operating costs are the actual ore extraction costs (often contracted out) and the cost for calcining. As would be expected, underground mines in the West are much more expensive than surface mines. In Tennessee, the two most important parts of these costs are in ore haulage to the mills by truck and in the actual ore extraction (both costs are contained within the mine operating cost).

Royalty costs for western deposits on Federal land were calculated as 5 pct of the estimated mine-mouth value. The State severance tax for phosphate in Idaho, Montana, North Carolina, Tennessee, Utah, and Wyoming is either small or nonexistent. Idaho and Wyoming have a 2-pct severance tax based on the value after mining. Montana's 0.5-pct rate is also based on the value after mining. North Carolina, Tennessee, and Utah have no State severance tax for phosphate. Florida has a significant State severance tax; $1.84 per ton of rock product is the new rate, enacted for 1981. It is not based on the value after mining, as it had been in the past; rather, it is strictly the rate times the units recovered. Each year this rate will be updated based on producer-price indexes. The State severance tax is included in the column labeled "Other" on table 6, along with the property, State, and Federal tax plus any royalty. These costs are greater for nonproducers because in most cases the overall total costs and revenues necessary to cover them are greater.

TABLE 6. - Operating costs for domestic phosphate operations

(All costs are expressed as January 1981 dollars per metric ton of product on a weight-averaged basis)

	Mine	Mill	Other[1]	Total	Average total cost (f.o.b. mill)	Transportation to plant or port[2]
Florida:						
Producers........	$9.20	$11.10	$2.60	$22.90	$27.80	$4.30
Nonproducers.....	10.00	14.10	7.60	31.70	46.00	5.00
North Carolina.....	W	W	W	W	W	W
Tennessee:						
Producers........	12.90	2.70	.40	16.00	17.30	1.40
Nonproducers.....	W	W	W	W	W	W
Idaho:						
Producers........	10.00	15.50	3.10	28.60	33.90	2.60
Nonproducers.....	18.90	15.50	2.30	36.70	43.60	2.40
Montana...........	W	W	W	W	W	W
Utah:						
Producers........	W	W	W	W	W	W
Nonproducers:						
Surface........	15.90	13.70	8.60	38.20	53.50	12.80
Underground....	31.40	39.00	7.70	78.10	94.30	14.70
Wyoming:						
Nonproducers:						
Surface........	21.70	12.40	6.70	40.80	58.80	8.50
Underground....	46.90	28.30	15.30	90.50	125.30	10.60

W Withheld to avoid disclosing individual deposit confidential information.

[1]Includes all property, State, Federal, and severance taxes plus any royalty.

[2]Transportation to ports in Florida and to acid or elemental plants in the West (Idaho, Utah, Wyoming, and Montana) and Tennessee. These transportation costs primarily represent the cost of rail transport only.

Although not included in the individual property analyses, transportation costs are also listed on table 6. In Florida these represent the rail costs to the ports of Tampa and Jacksonville. If the rock product is actually being sent to a nearby acid plant, the costs will most likely be less. In the West, costs shown on the table are the costs of transportation to local acid or elemental plants. Since most of these plants are in Idaho, distances are shorter in that State than for deposits in Utah and Wyoming, which for the purposes of this study, send their rock to plants in Idaho.

Table 7 shows the average capital costs estimated for this study to develop the nonproducing deposits in the United States at different ore capacities. These costs represent the costs to acquire, explore, develop, and equip a new mine site, along with the construction of any necessary mine and mill plants and buildings. Costs associated with compliance with environmental regulations and permitting are included to the extent known. Environmental constraints to development are discussed in appendix C. Capital costs for a new mine in Tennessee are not shown since there is

TABLE 7. - Estimated capital costs to develop nonproducing phosphate deposits in the United States

	Thousand metric tons		Millions of January 1981 dollars					
	Ore per year	Product per year	Exploration, acquisition, and development	Mine capital	Mill capital	Total capital	Cost per annual ton ore	Cost per annual ton product
Southeast.....	2,500	450	9.6	8.9	21.3	39.8	15.90	88.40
	5,600	1,000	32.2	16.1	38.3	86.6	15.50	86.60
	15,600	2,400	74.6	34.5	71.4	180.5	11.60	75.20
West:								
Surface.....	1,100	800	3.7	10.2	58.7	72.6	66.00	90.80
Underground.	1,200	700	17.8	15.9	73.0	106.7	88.90	152.40

only one Tennessee nonproducing deposit in this evaluation and the costs would be considered confidential. In 1977 a developing operation in Tennessee that could produce approximately 1 million tons per year of product (from a number of small mines) would have cost approximately $10 million for mine and washer facilities (2).

COMPARISON OF SOUTHEASTERN AND WESTERN RESOURCES

As shown in the geology section, the in situ and feed grades in the West are considerably higher than those in the Southeast. The western deposits start at over 20 pct P_2O_5 on the average, whereas the southeastern deposits average under 10 pct P_2O_5. Both areas upgrade to approximately 30 pct P_2O_5 (slightly greater in the Southeast); i.e., more upgrading is necessary for the deposits in the Southeast that for those in the West. Processing costs in the West, however, are equal to or greater than those in the Southeast because of calcining costs, which tend to be high because of their added energy requirements.

Although mine recoveries in the West are slightly higher than those in the Southeast, and mill recoveries are very similar, total operating costs in the West are higher than those in the Southeast, largely because of the higher mine operating costs. Mining costs are greater in the West because of larger amounts of overburden, the amount of blasting required, and the smaller size of the operations (providing less economies of scale).

One of the more significant differences between the western and southeastern deposits is in transportation costs. Table 6 shows the costs to transport phosphate rock to ports in Florida and North Carolina (since these are the ports of departure for exports) and to local acid plants and elemental plants in the West and Tennessee (since virtually all of this material is consumed internally). In Florida transporting phosphate rock to the appropriate ports costs just over $4 per ton; transporting a ton of phosphate rock to local plants in Idaho costs about $2.50, and it could cost about $13.50 to ship rock from Utah to existing plants in Idaho. If rock from Wyoming were sent to plants in Idaho, it would cost about $9.50 per ton. The transportation costs for deposits in Utah and Wyoming are high because most of the processing plants are presently in Idaho, which is the assumed destination for their production. Quite likely, however, processing plants will be built in Utah and Wyoming if a large phosphate mining industry is established in those States. Once at the plants, the western rock must still be processed and

transported, thus incurring additional costs before reaching a market. Since the major domestic rock and acid markets are in the East and Midwest, the southeastern deposits clearly have a cost advantage over those in the West. The transport distances are shorter; barges can be used instead of rail, which would lower costs; and the access routes (mainly the Mississippi River) are more direct to the domestic agricultural markets in addition to the export markets. Western phosphate, however, has a natural market in the agricultural industries of the Western States.

The above factors provide a definite economic advantage to the southeastern deposits over the western deposits to supply most of the domestic and export markets. Southeastern deposits will not lose this advantage in the foreseeable future.

As described in the resource section, over 60 pct of the demonstrated resources in the United States lie in the southeastern deposits, although vast quantities of phosphate in the West at the inferred and hypothetical levels represent a significant future resource.

AVAILABILITY OF DOMESTIC PHOSPHATE RESOURCES

The potential tonnage and cost for each of the 130 mines and deposits evaluated have been aggregated onto phosphate rock availability curves, which illustrate the comparative costs associated with any given level of potential total output and provide an estimate of what the average phosphate rock price (in January 1981 dollars) would likely have to be for a given tonnage to be potentially available. Costs reflect not only capital and operating costs, but also all Federal, State, and local taxes an operation incurs selling phosphate rock f.o.b. mill.

TOTAL AVAILABILITY

Approximately 6.4 billion tons of phosphate rock is potentially recoverable from all domestic deposits evaluated at the demonstrated resource level. As shown in figure 14, approximately 1.3 billion tons of phosphate rock is potentially recoverable at costs ranging up to \$30 per ton, which is only 20 pct of the total recoverable tonnage. Approximately 2.4 billion additional tons of phosphate rock is potentially recoverable at costs ranging between \$30 and \$40 per ton. This means that at a long-run constant dollar price for phosphate rock of \$45 per ton (approximately 1.5 times the January 1981 price), 3.7 billion tons of phsophate rock is potentially available. Not shown on the curve are just over 700 million tons of phosphate rock costing over \$100 per ton.

Figure 15 shows the total availability of phosphate rock from Florida and North Carolina deposits, where nearly two-thirds of all evaluated resources occur. Nearly 4 billion tons of phosphate rock is potentially recoverable from Florida and North Carolina from demonstrated resources. At costs ranging up to \$30 per ton, approximately 1 billion tons is potentially recoverable, 25 pct of the total from these two States and almost 85 pct of the total for the United States potentially available at a long-run price of \$30. At \$45, potentially available phosphate rock from Florida and North Carolina increases to 3 billion tons.

Figure 16 shows the total availability of phosphate rock from the deposits in Idaho, Montana, Utah, and Wyoming. Nearly 2.5 billion tons of phosphate rock is potentially recoverable from these deposits, although many may have a production cost exceeding \$100 per ton and are therefore not represented on the curve. Only 300 million tons is potentially available at \$30 per ton, increasing 400 million tons at \$45 per ton.

Phosphate rock market prices vary significantly depending on the product grade. The three curves in figure 17 were developed for specific product-grade ranges. The product-grade ranges are less than 30.2 pct P_2O_5 (low grade), between 30.2 and 32 pct P_2O_5 (medium grade), and greater than 32 pct P_2O_5

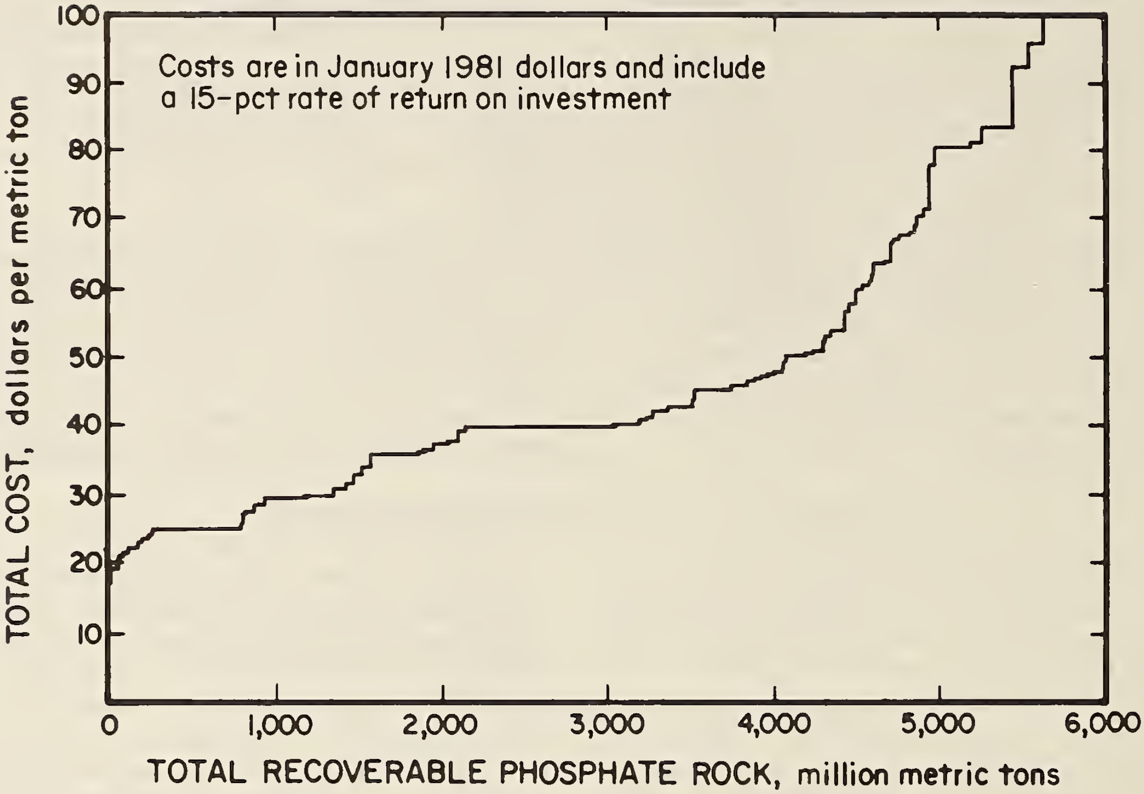

FIGURE 14. - Phosphate rock potentially recoverable from all domestic deposits.

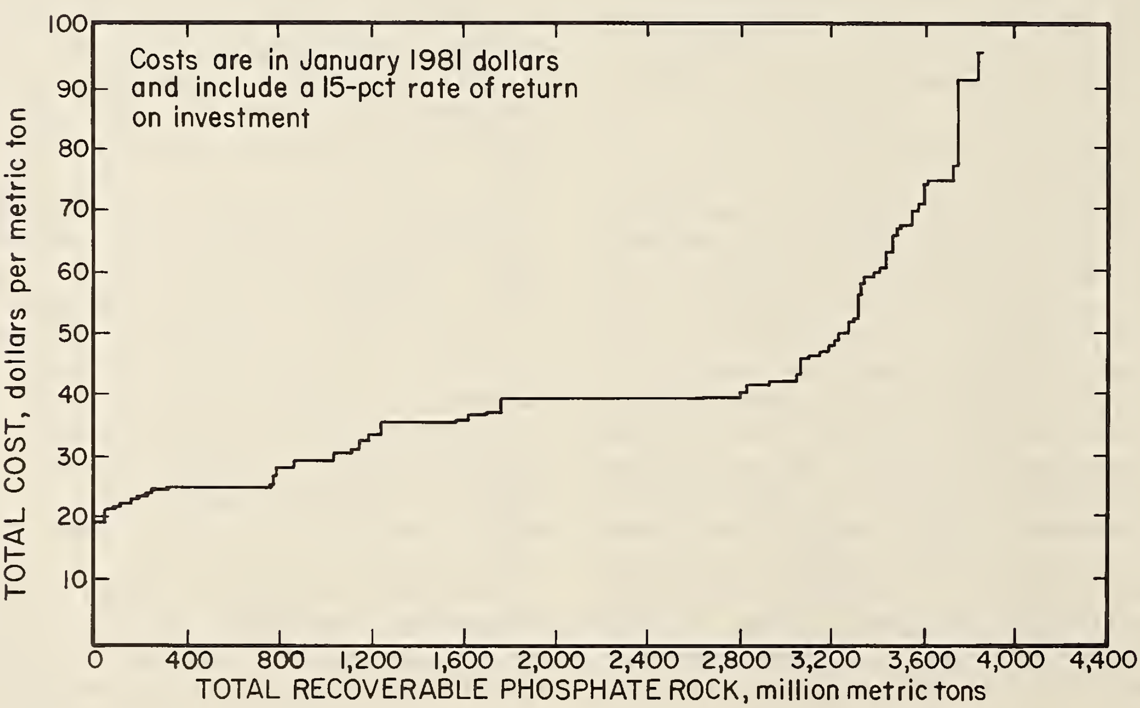

FIGURE 15. - Phosphate rock potentially recoverable from all Florida and North Carolina deposits.

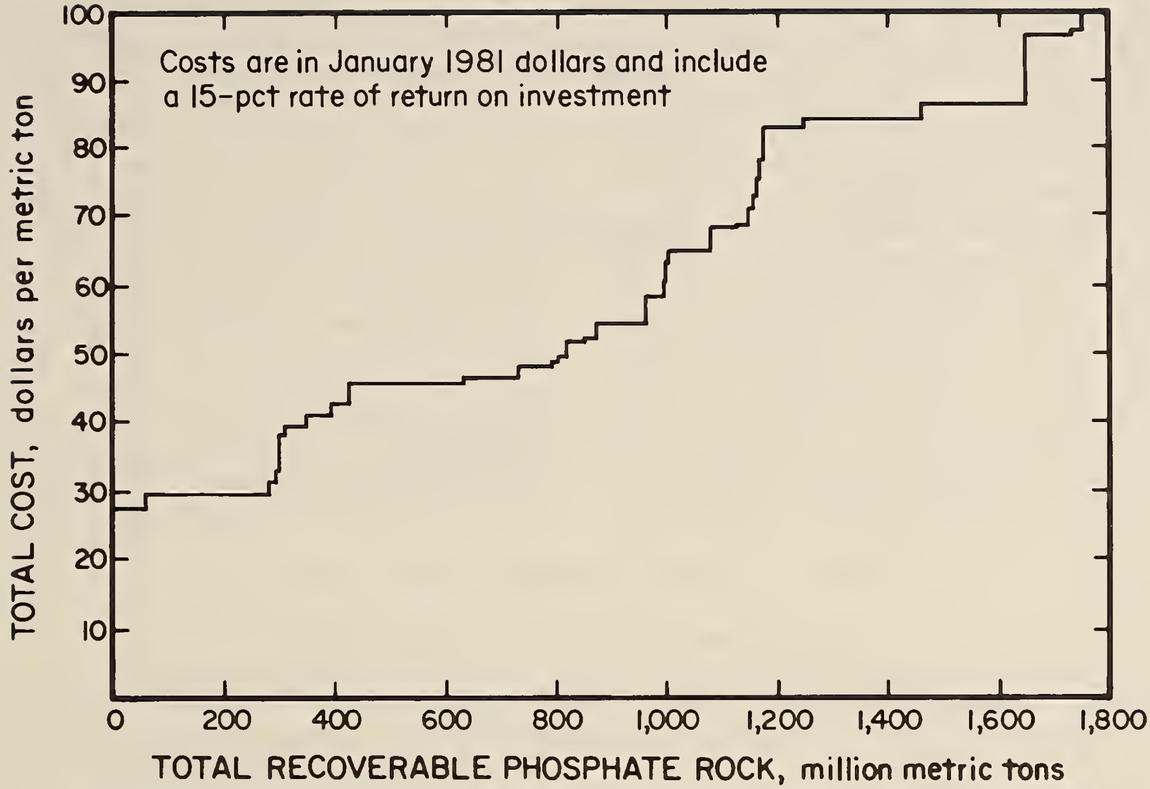

FIGURE 16. - Phosphate rock potentially recoverable from all western deposits.

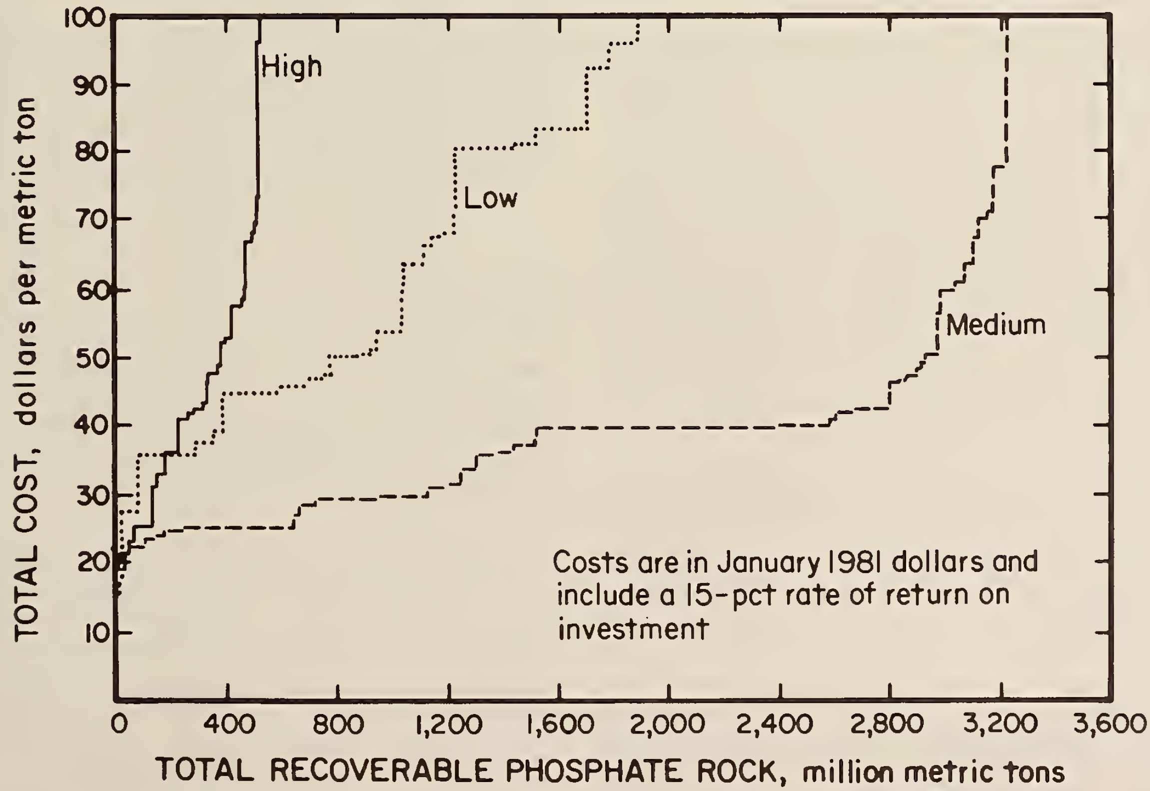

FIGURE 17. - Phosphate rock potentially recoverable from all domestic deposits, at selected grade ranges.

(high grade). The average prices for phosphate rock from domestic mines in 1981 are shown in table 8 (17). Of the total 6.4 billion tons of recoverable product evaluated in this study, approximately 40 pct is from low-grade deposits, 50 pct from medium-grade deposits, and 10 pct from high-grade deposits. The curves show that at a long-run cost of $30 per ton, almost 100 million tons of low-grade rock, more than 1 billion tons of medium-grade rock, and over 100 million tons of high-grade rock are potentially available. At $60 per ton, approximately 1 billion low-grade tons, 3 billion medium-grade tons, and 0.5 billion high-grade tons of rock are potentially available.

Figure 18 shows the availability of phosphate rock from all domestic mines and deposits with separate curves for producers and nonproducers. The curve for producers shows that at costs ranging up to $30 per ton, almost 1.2 billion tons of phosphate rock is potentially recoverable, nearly three-quarters from Florida and North Carolina. At approximately $40, total availability from these mines increases only to 1.3 billion tons, again nearly three-quarters from Florida and North Carolina. The curve for non-producers shows that at costs ranging up to $40 per ton, nearly 2 billion tons is potentially recoverable, increasing to 3 billion at $60. Five billion tons could

TABLE 8. - 1981 phosphate rock prices

(Dollars per metric ton, f.o.b. mine)

Grade, pct P_2O_5	Domestic	Export	Average
	United States		
Plus 33.9	$32.00	$45.54	$41.08
32.95 to 33.9	32.81	37.93	36.13
32 to 32.95	28.35	34.36	31.08
30.2 to 32	23.60	31.75	24.76
27.5 to 30.2	27.11	28.15	27.35
Minus 27.5	9.20	NAp	9.20
Average	23.82	33.93	26.08
	Florida and North Carolina--Land Pebble		
Plus 33.9	$32.00	$45.54	$41.08
32.95 to 33.9	32.81	37.93	36.13
32 to 32.95	25.26	33.93	29.14
30.2 to 32	23.57	31.29	24.61
27.5 to 30.2	31.66	27.54	30.55
Minus 27.5	14.71	NAp	14.71
Average	25.17	33.74	27.17
	Western States		
32 to 32.95	$35.94	$37.08	$37.15
30.2 to 32	24.25	37.88	27.42
27.5 to 30.2	10.46	35.33	14.93
Minus 27.5	9.26	NAp	9.26
Average	18.06	37.09	21.98
	Tennessee		
27.5 to 30.2	$15.93	NAp	$15.93
Minus 27.5	8.75	NAp	8.75
Average	12.01	NAp	12.01

NAp Not applicable.

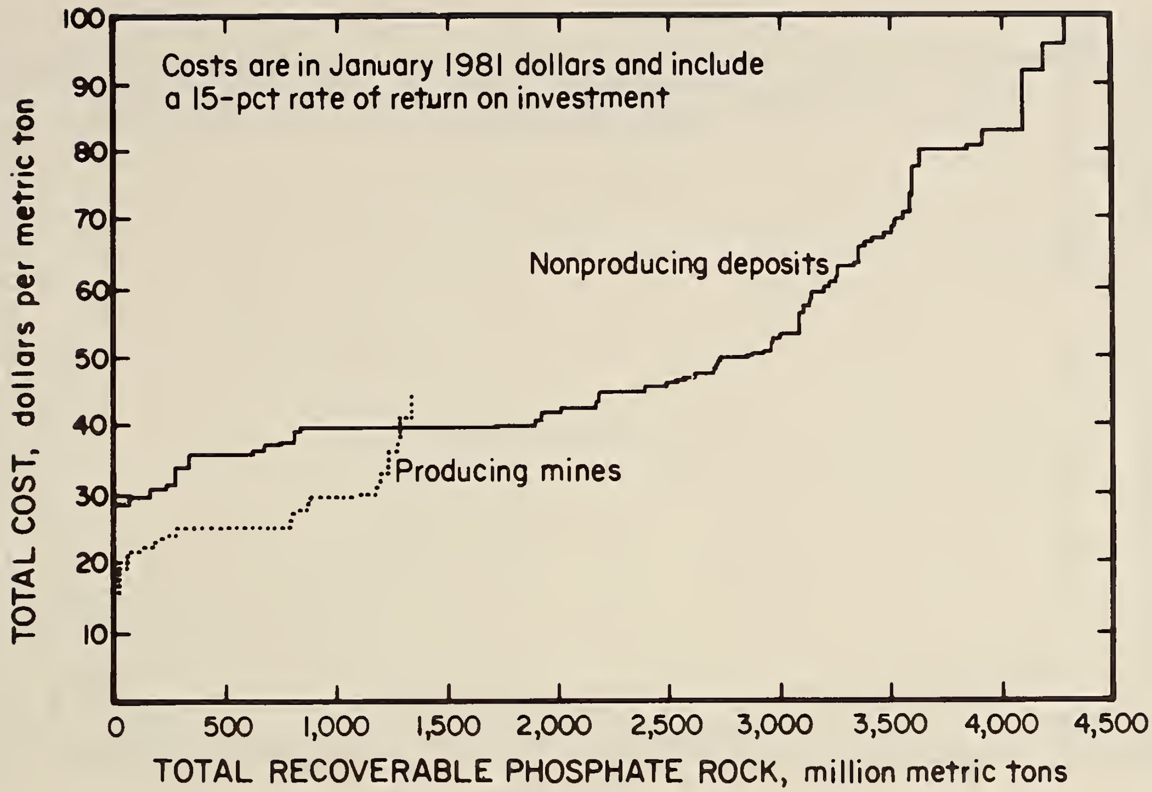

FIGURE 18. - Phosphate rock potentially recoverable from producing mines and nonproducing deposits.

potentially be available from all nonproducing deposits. Approximately 60 pct of the total potential tonnage from nonproducing deposits is in Florida and North Carolina.

POTENTIAL ANNUAL AVAILABILITY

Another way of illustrating phosphate availability is to deisaggregate the total resource-availability curve and show potential production on an annual basis. For analysis, separate annual-availability curves have been constructed for producing and proposed operations.

Potential annual production of phosphate from producing operations is shown from 1981 through 2000. The curves for producing operations show the production capacity of existing mines, including planned expansions when known. It was assumed that all operations produce at full (100 pct) capacity over the life of the mine.

Since no definite startup data is available for most of the nonproducers, it was assumed that preproduction began in a base year (N) of the analysis, which cannot be connected with an actual year since production from many of these deposits is not expected in the near future. However, the annual curves for nonproducers do show the required lead times before production can begin and therefore are important in that they show the potential annual production and associated costs of the mines of the future. In these curves, all nonproducers assumedly begin preproduction development at the same time; consequently the tonnage available in a given year is likely overstated since not all the nonproducers will begin preproduction simultaneously.

Figure 19 illustrates potential annual production from domestic producing mines. These mines are high-grade, low-cost operations, mostly located in the Southeast. The analyses indicate that a

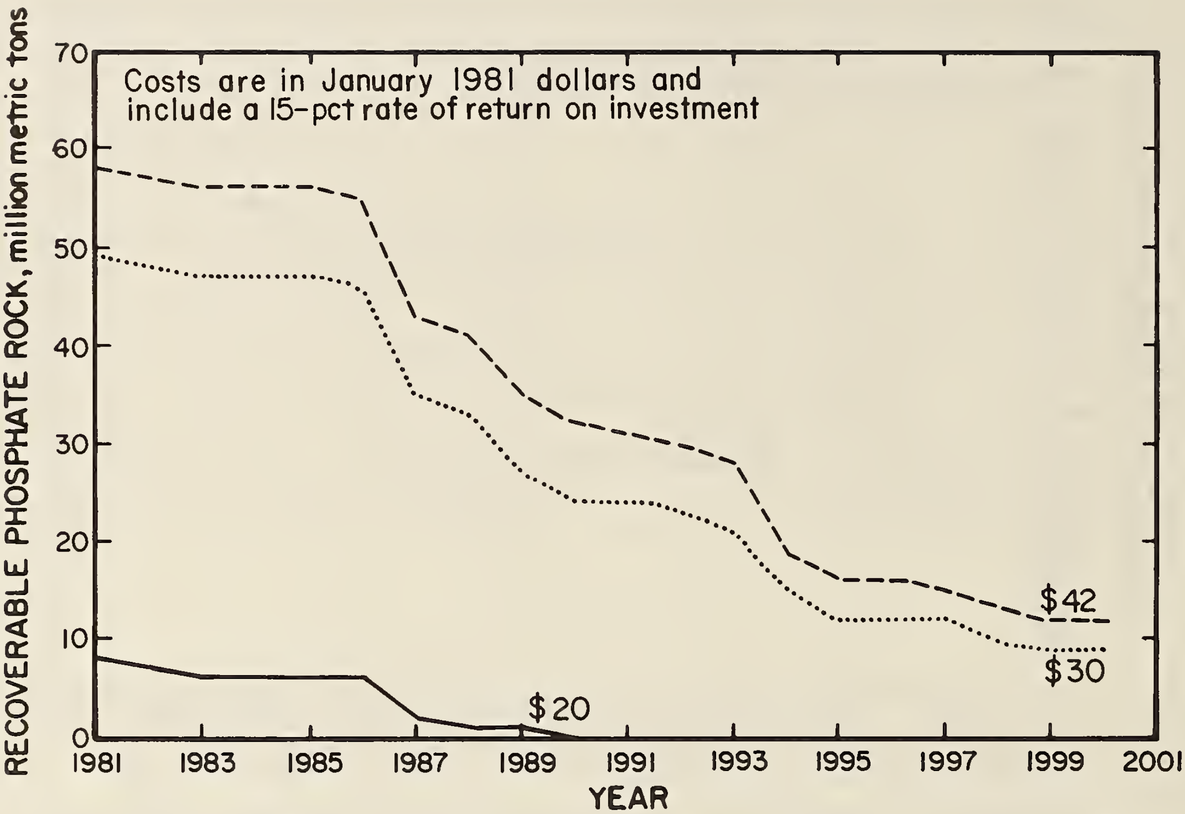

FIGURE 19. - Potential annual availability of phosphate rock from producing mines.

maximum of 49 million tons of phosphate was potentially available in 1981 at $30 per ton and that 59 million tons was available at $42 per ton, compared with an actual 1981 production of 52.9 million tons (17). Potential annual production from these mines (assuming full capacity) will begin to decline slowly until 1986, and then drop sharply as some mines become exhausted. However, because actual production since 1981 has been at less than full capacity, the decline of low-cost production will actually be delayed for several more years and will likely be more gradual than indicated on the curve. For production levels to be maintained, current capacities of the remaining mines may have to be expanded, and new lower grade deposits (some of which are already in developmental stages) will have to be brought on line.

Figure 20 illustrates potential annual production for nonproducing deposits. At both cost ranges of up to $45 and $90 per ton, phosphate rock production would initially increase dramatically as deposits came on line. From zero production in year N, output could rise in year N+4 to 50 million tons at costs ranging up to $45 per ton, and to 97 million tons at costs ranging up to $90 per ton. Production would peak in the year N+4 and remain relatively constant with a slight decline in annual production by the year N+18. Phosphate that could be produced for less than $30 per ton from nonproducers would peak at 7 million tons in the year N+3 and remain constant through the year N+18. This would indicate that most of the low-cost phosphate comes from currently producing mines, which is not surprising since the nonproducing deposits are usually of lower quality and will have higher costs.

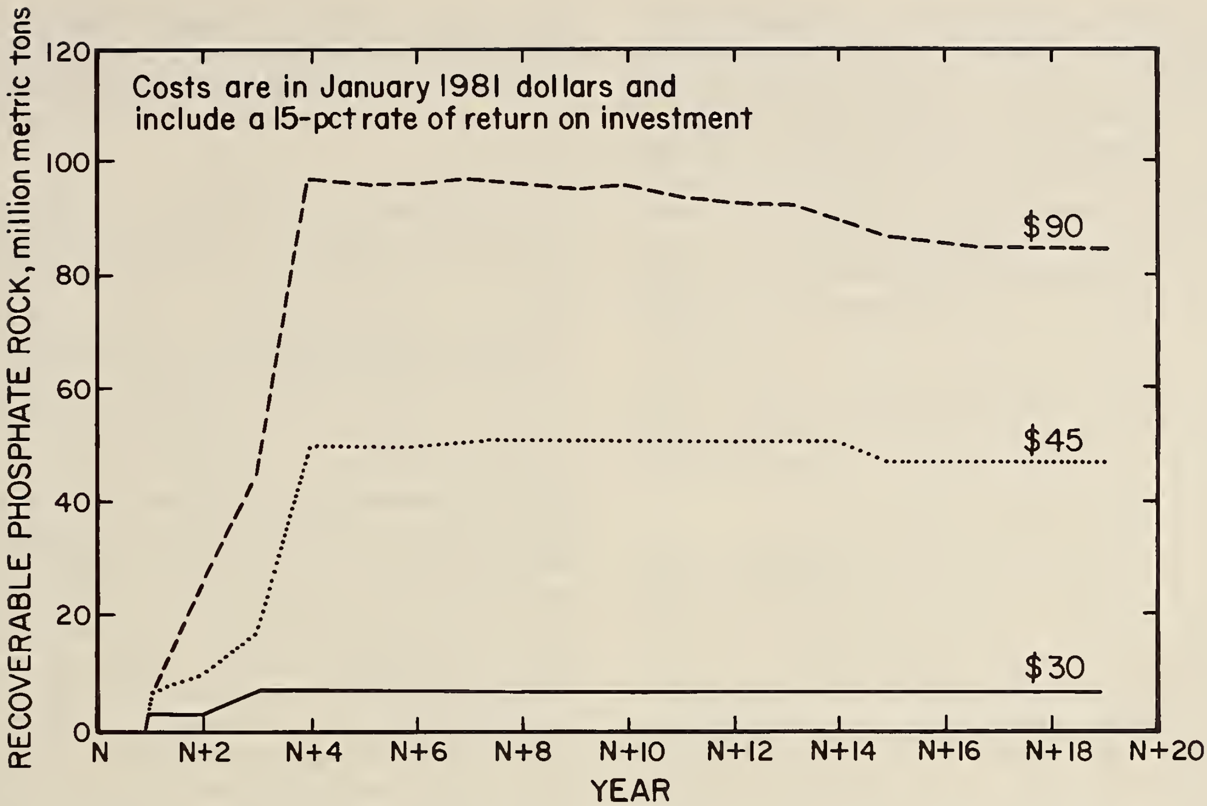

FIGURE 20. - Potential annual availability of phosphate rock from nonproducing deposits.

CONCLUSIONS

The agricultural industry is dependent upon the supply of fertilizers derived from phosphate rock. The adequacy of the future supply potential of phosphate rock from domestic sources has been disputed in recent years. In an attempt to assess domestic phosphate rock resources, the Bureau of Mines evaluated 130 domestic phosphate mines and deposits. The selected deposits included all resources of phosphate rock at the demonstrated level that met the criteria of this study and that can be mined and milled with current technology.

Nearly 6.4 billion tons of phosphate rock is recoverable from domestic demonstrated resources. The southeastern deposits contain about 3.9 billion tons of recoverable phosphate rock, approximately 60 pct of the total domestic resource. The western deposits contain most of the remaining 2.5 billion tons of recoverable phosphate rock. The very small resources in Tennessee play only a minor role in the total domestic-resource picture.

The 6.4 billion tons of demonstrated phosphate rock resources in the United States includes both low- and high-cost deposits. This study indicates that approximately 1.3 billion tons of phosphate rock could be available at costs ranging up to $30 per ton, 3 billion tons at under $40 per ton, 3.6 billion tons at under $45 per ton, and 4.5 billion tons at under $60 per ton. The balance of recoverable resources comprises potential production from deposits that would cost from $60 to well over $100 per ton. These deposits would not likely be needed for many years, and their development is dependent upon future technological innovations.

Of the total U.S. demonstrated phosphate rock resource, only 20 pct is available from existing mines. At full-capacity levels, annual production from

the existing, low-cost phosphate operations in the United States (particularly in Florida) will likely decline in the next decade. To maintain or increase these annual production levels, new deposits will have to be developed from the remaining demonstrated resource, which accounts for approximately 80 pct of total U.S. demonstrated resources. Based on the results of this study, and assuming current technology and product standards, phosphate from these new operations will be more expensive to produce than that from existing operations, requiring a price increase in real terms of about 50 pct above 1981 levels.

In addition to its large demonstrated phosphate rock resource, the United States contains vast, untapped resources at the inferred and hypothetical levels. Although not individually evaluated in this study, these resources represent a significant future potential for the United States. It is estimated that some 7 billion tons of potentially recoverable phosphate rock exists at the inferred level (over 80 pct of which is in the Southeast), and over 24 billion tons of potentially recoverable phosphate rock exists at the hypothetical level (over 60 pct of which is also in the Southeast).

New deposits will likely be discovered (particularly offshore deposits along the eastern seaboard), low-grade material not included in this analysis could become economically minable, or technological advances could enable processing high-magnesium oxide material or mining deeper deposits. Each of these factors could greatly increase the amount of phosphate available and ensure a continued high level of future production from domestic resources.

Of immediate interest is more than 2 billion tons of recoverable phosphate rock in Florida at the identified resource level that has a high content of magnesium oxide and is presently considered unnacceptable by the industry owing to the higher beneficiation costs of producing an acceptable acid plant feed. Given the progress several phosphate companies and the Bureau of Mines have made in improving beneficiation technologies to lower the grade of magnesium oxide in the phosphate rock product, this additional 2 billion tons of rock will likely become available in the near future.

The U.S. phosphate industry has been the world leader in the output of phosphate rock and related products but is now facing the challenges of higher production costs and foreign competition for export markets (particularly from North Africa and the Middle East). Although the U.S. phosphate resource potential is virtually unlimited, this study suggests that total production from phosphate mines now in operation will decline during the next decade, and new lower grade, higher cost mines will have to be developed to satisfy demand for U.S. phosphate rock and related products into the next century.

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APPENDIX A.--DOMESTIC PHOSPHATE DEPOSIT STATUS AND OWNERSHIP

Property name	Property status	Owner	Type of operation
		FLORIDA	
Acrefoot Johnson	Explored	Freeport Phosphate Mining Co	Surface.
Big Four	Producer	AMAX Inc	Do.
Bonny Lake Mine	do	W.R. Grace Co	Do.
Boyette and Fishawk	Explored	Agrico Chemical Co	Do.
Brooker-Dukes	do	Kerr-McGee Chemical Corp	Do.
C.F. Hardee Phosphate Complex	Producer	C.F. Industries Inc	Do.
Christina Reserve	Explored	Mobil Chemical Co	Do.
Clear Springs	Producer	IMC Corp	Do.
Cooks Hammock #1	Explored	Monsanto Co	Do.
Cooks Hammock #2	do	Unidentified major paper company	Do.
David C. Turner Heirs	do	Heirs of D.C. Turner	Do.
Deep Creek	do	Occidental Chemical Co	Do.
Deseret Ranch	do	Mormon Church	Do.
Desoto-Manatee Reserve	Developing	AMAX Inc	Do.
Duette Mine	do	ESTECH	Do.
Durrance-Waters Tract	Explored	U.S.S. Agri-Chemicals	Do.
Farmland Hardee Mine	Developing	Farmland Industries Inc	Do.
Farmland Hillsborough Reserve	Explored	do	Do.
First Mississippi Chemical Tract	do	First Mississippi Chemical Corp	Do.
Fort Green Mine	Producer	Agrico Chemical Co	Do.
Fort Meade Mine #1	do	Mobil Chemical Co	Do.
Fort Meade Mine #2	do	Gardinier Inc	Do.
Four Corners	Developing	W.R. Grace Co	Do.
Fridovich	Explored	Agri-Leis Corp	Do.
Hard Rock Deposit	do	T/A Minerals	Do.
Hard Rock Colloidal Clay	Producer	Anco-Kellog-Howard-Loncala-Sun	Do.
Hardee Mine	Explored	First Mississippi Chemical Corp	Do.
Hardee West Prospect	do	Various ownerships	Do.
Hardrock Deposit	do	do	Do.
Haynesworth Mine	Producer	Brewster-American Cyanamid-Kerr-McGee	Do.
Hillsborough Co.-Farmland Brewster.	Explored	Pruitt-Thompson-Jameson-Simms	Do.
Hookers Prairie	Producer	W.R. Grace Co	Do.
Hopewell Mine	Developing	Noranda Mines Ltd	Do.
Hunt Brothers Ranch	Explored	IMC Corp	Do.
Keys Property	do	do	Do.
Kingsford Mine	Producer	do	Do.
La Crosse Deposit	Explored	Kerr-McGee Chemical Corp	Do.
Little Payne Creek	do	USS Agri-Chem-Gardinier-others	Do.
Lonesome Mine	Producer	Brewster Phosphates and American Cyanamid	Do.
Manatee North	Explored	W.R. Grace Co	Do.
Manatee South	do	do	Do.
Manson-Jenkins	do	U.S.S. Agri-Chemicals	Do.
Mobil Area	do	Various ownerships	Do.
N.E. Manatee Swift-Grace	do	W.R. Grace Co. and others	Do.
Nichols Mine	Producer	Mobil Chemical Co	Do.
No. Columbia County #2	Explored	Southern Resin Corp	Do.
Noralyn-Phosphoria	Producer	IMC Corp	Do.
North Lake City Deposit	Explored	Kerr-McGee Chemical Corp	Do.
Northeast Manatee-Texaco	do	Various ownerships	Do.
Osceola National Forest	do	U.S. Forest Service	Do.
Payne Creek-Palmetto	Producer	Agrico Chemical Co	Do.
Pierce-Pebbledale	Explored	do	Do.
Pine Level Deposit	do	AMAX Inc	Do.
Polk County Mine	Producer	T/A Minerals	Do.
Rockland Mine	do	U.S.S. Agri-Chemicals and Freeport Phosphate Co.	Do.
Rutland-Corvin-Vale	Explored	IMC Corp	Do.
Saddle Creek-Ebersbach	Producer	Agrico Chemical Co	Do.
Silver City Mine	Producer	ESTECH	Do.
South Fort Meade	Developing	Mobil Chemical Co. and others	Do.
South Hardee	Explored	Gardinier Inc	Do.
Stanaland Ranch	do	IMC Corp	Do.
Suwannee River Mine	Producer	Occidental Chemical Co	Do.
Swift Creek Mine	do	do	Do.
Swift-Durrance Area	Explored	Various ownerships	Do.
Texaco Manatee	do	Texaco Inc	Do.
Waters Tract	do	U.S.S. Agri-Chemicals	Do.
Watson Mine	Producer	ESTECH	Do.

Property name	Property status	Owner	Type of operation
FLORIDA--Continued			
Wingate Creek Mine.................	Developing...	Beker Industries............................	Surface.
Zolfo Springs Area Small Ownerships	Explored.....	Various ownerships..........................	Do.
Zolfo-Stauffer.....................	.....do......	Stauffer Chemical Co........................	Do.
IDAHO			
Champlease-Mountain Fuel-Husky #1..	Developing...	Beker Industries............................	Surface.
Conda Mine and Smokey Canyon.......	Producer.....	J.R. Simplot Co.............................	Do.
Diamond Creek......................	Explored.....	Alumet Corp.................................	Do.
Gay Mine-Dry Valley................	Producer.....	J. R. Simplot Co. and FMC Corp..............	Do.
Henry Mine.........................	.....do......	Monsanto Co.................................	Do.
Maybe Canyon Mine..................	.....do......	Beker-Western Fertilizer Consortium (Conda Partnership).	Do.
N. Henry-Trail-Caldwell-Blackfoot..	Developing...	Monsanto Co.................................	Do.
Wooley Valley-Rasmussen Ridge......	Producer.....	Stauffer Chemical Co........................	Do.
MONTANA			
Warm Springs Creek.................	Producer.....	Cominco American Inc........................	Underground.
NORTH CAROLINA			
Lee Creek Mine.....................	Producer.....	Texas Gulf Chemical Corp....................	Surface.
North Carolina Phosphate...........	Developing...	North Carolina Phosphate Corp...............	Do.
TENNESSEE			
Hickman and Maury Co. properties...	Producer.....	M.C. West Inc...............................	Surface.
Hooker Chemical properties.........	.....do......	Hooker Chemical Co..........................	Do.
Monsanto properties................	.....do......	Monsanto Co.................................	Do.
Stauffer Chemical Co. property.....	.....do......	Stauffer Chemical Co. and others............	Do.
Tennessee Valley Authority Reserves	Past producer	Tennessee Valley Authority..................	Do.
UTAH			
Central Wasatch Range #1...........	Explored.....	Public land, unleased.......................	Surface.
Central Wasatch Range #2...........	.....do......	.....do.....................................	Underground.
Crawford Mountains #1..............	.....do......	Stauffer Chemical Co........................	Surface.
Crawford Mountains #2..............	.....do......	.....do.....................................	Do.
Crawford Mountains #3..............	.....do......	.....do.....................................	Underground.
Crawford Mountains #4..............	.....do......	.....do.....................................	Do.
Crawford Mountains #5..............	.....do......	.....do.....................................	Do.
Flaming Gorge #1...................	.....do......	Public land, unleased.......................	Surface.
Flaming Gorge #2...................	.....do......	.....do.....................................	Underground.
Flaming Gorge #3...................	.....do......	.....do.....................................	Do.
Northern Wasatch Range.............	.....do......	.....do.....................................	Surface.
Vernal Field #1....................	.....do......	U.S. Steel..................................	Do.
Vernal Field #2....................	Explored.....	.....do.....................................	Do.
Vernal Field #3....................	.....do......	.....do.....................................	Underground.
Vernal Field #4....................	.....do......	.....do.....................................	Do.
Vernal Field #5....................	.....do......	.....do.....................................	Do.
Vernal Mine........................	Producer.....	Chevron.....................................	Surface.
WYOMING			
Gros Ventre Range #1...............	Explored.....	Public land, unleased.......................	Surface.
Gros Ventre Range #2...............	.....do......	.....do.....................................	Underground.
Hoback Range #1....................	.....do......	.....do.....................................	Surface.
Hoback Range #2....................	.....do......	.....do.....................................	Do.
Hoback Range #3....................	.....do......	.....do.....................................	Underground.
S.E. Wind River Range #1...........	.....do......	.....do.....................................	Surface.
S.E. Wind River Range #2...........	.....do......	.....do.....................................	Underground.
Salt River Range #1................	.....do......	.....do.....................................	Surface.
Salt River Range #2................	Explored.....	.....do.....................................	Underground.
Salt River Range #3................	.....do......	.....do.....................................	Do.
Snake River #1.....................	.....do......	.....do.....................................	Surface.
Snake River #2.....................	.....do......	.....do.....................................	Underground.
Snake River #3.....................	.....do......	.....do.....................................	Surface.
Snake River #4.....................	.....do......	.....do.....................................	Underground.
Snake River #5.....................	.....do......	.....do.....................................	Do.
South Ridges #1....................	.....do......	.....do.....................................	Surface.
South Ridges #2....................	.....do......	.....do.....................................	Underground.
South Ridges #3....................	.....do......	.....do.....................................	Do.
Sublette Range #1..................	Past producer	.....do.....................................	Surface.
Sublette Range #2..................	Explored.....	.....do.....................................	Underground.
TUNP #1............................	.....do......	.....do.....................................	Surface.
TUNP #2............................	.....do......	.....do.....................................	Do.
TUNP #3............................	.....do......	.....do.....................................	Underground.
TUNP #4............................	.....do......	.....do.....................................	Do.
Wyoming Range #1...................	.....do......	.....do.....................................	Surface.
Wyoming Range #2...................	.....do......	.....do.....................................	Underground.

APPENDIX B.--THE ZELLARS-WILLIAMS COST MODEL FOR FLORIDA PHOSPHATE--DESCRIPTION OF TYPICAL CASES

The following are descriptions of the six Zellars-Williams, Inc., cost models for Florida phosphate deposits. The descriptions and following discussions are taken almost entirely from the Zellars-Williams final report entitled "Evaluation of the Phosphate Deposits of Florida Using the Minerals Availability System" (20).

Case I

Large mine (2,750,000 to 4,500,000 tons of product per year).

Low matrix X in the 2.8- to 3.5-yard-per-ton range.

High pebble-to-concentrate ratio (that is, pebble ranging from 40 to 50 pct of the total product).

Average product above 32 pct P_2O_5.

Mine at least 10 years old.

Case II

Medium-sized mine (1,360,000 to 2,750,000 tons of product per year).

Reserve characteristics same as case I.

Mine at least 10 years old.

Case IIA

Medium-sized mine (1,360,000 to 2,750,000 tons of product per year).

Reserve characteristics same as case I.

Mine not more than 2 years old.

Case III

Small mine (900,000 to 1,360,000 tons of product per year).

Reserve characteristics same as case I.

Case IV

Large mine (2,750,000+ tons of product per year).

High matrix X in the 3.8- to 4.5-yard-per-ton range.

Low pebble-to-concentrate ratio (that is, pebble ranging from 10 to 20 pct of the total product).

Lower P_2O_5 grade (30.7 to 31.1 pct P_2O_5) with higher MgO content.

Case V

Small mine (900,000 to 1,800,000 tons of product per year).

Reserve characteristics similar to case IV.

Cases I, II, IIA, and III represent existing mines with high-grade reserves typical of the active mining area in central Florida. Cases IV and V represent new or proposed mines with low-grade reserves typical of the areas immediately to the south, but applicable to other areas in the State. Table B-1 summarizes production cost data developed for the six cases, and tables B-2 through B-13 provide a more detailed itemization of costs.

Factors Affecting Production Costs

The detailed study of production cost data for existing and proposed mines led to identifying the key factors affecting production costs. The two variables found to have the greatest influence on production costs were (1) matrix X (recoverable product per unit volume of ore) and (2) mine size (production rate).

TABLE B-1. - Mining and milling production cost summary

	Dollars per ton of product (dry, f.o.b. mill)					
	Case I	Case II	Case IIA	Case III	Case IV	Case V
Direct cost	12.91	13.91	13.53	16.14	15.41	16.38
Indirect cost	.80	1.01	.86	1.31	.78	1.26
Fixed cost	1.46	1.46	1.46	1.46	1.85	1.85
Total	15.17	16.38	15.85	18.91	18.04	19.49

TABLE B-2. - Production cost of typical large mine in higher quality ore (case I)

Cost summary by category	Total operating cost per ton of product (dry, f.o.b.)	Cost per ton of ore (dry, f.o.b. mill)		
		Mine	Mill	Total
Raw materials, utilities, and support:				
Power	$3.10	$0.31	$0.46	$0.77
Reagents	1.19	0	.29	.29
Fuel (gasoline and diesel)	.04	.01	0	.01
Fuel (fuel oil drying)[1]	2.58	0	.64	.64
Supplies	.35	.07	.02	.09
Mobile mine-support equipment	.14	.03	0	.03
Outside services (dam construction and reclamation)	.78	.19	0	.19
Direct labor:				
Operating	1.46	.20	.16	.36
Supervisory	.40	.06	.04	.10
Plant maintenance:				
Labor	.50	.06	.06	.12
Supervision	.25	.03	.03	.06
Maintenance parts and supplies	1.32	.16	.17	.33
Replacement mine pipe	.21	.05	0	.05
Payroll overhead (fringes, etc.)	.59	.08	.07	.15
Subtotal direct costs	12.91	1.25	1.94	3.19
Administrative, technical, clerical labor	.45	.06	.06	.12
Payroll overhead (administrative)	.12	.01	.01	.02
Facilities maintenance and supplies	.07	.01	.01	.02
General overhead (including head office, charges, exploration, and research)	.16	.02	.02	.04
Subtotal indirect costs	.80	.10	.10	.20
Total direct and indirect costs	13.71	1.35	2.04	3.39
Local taxes	1.40	.29	.05	.34
Insurance	.06	.01	.01	.02
Subtotal fixed costs	1.46	.30	.06	.36
Grand total cost	15.17	1.65	2.10	3.75

[1]Rock may or may not be dried in all cases since phosphoric acid processes are now available for the use of wet rock. Cost presented is for dry rock.

TABLE B-3. - Production cost of typical medium-sized mine in higher quality ore (case II)

Cost summary by category	Total operating cost per ton of product (dry, f.o.b.)	Cost per ton of ore (dry, f.o.b. mill)		
		Mine	Mill	Total
Raw materials, utilities, and support:				
Power	$2.40	$0.24	$0.36	$0.60
Reagents	1.51	0	.38	.38
Fuel (gasoline and diesel)	.06	.02	0	.02
Fuel (fuel oil drying)[1]	2.58	0	.65	.65
Supplies	.36	.07	.02	.09
Mobile mine-support equipment	.21	.05	0	.05
Outside services (dam construction and reclamation)	.63	.16	0	.16
Direct labor:				
Operating	1.80	.25	.20	.45
Supervisory	.53	.08	.05	.13
Plant maintenance:				
Labor	.63	.08	.08	.16
Supervision	.33	.04	.04	.08
Maintenance parts and supplies	1.89	.24	.24	.48
Replacement mine pipe	.22	.06	0	.06
Payroll overhead (fringes, etc.)	.76	.11	.09	.20
Subtotal direct costs	13.91	1.40	2.11	3.51
Administrative, technical, clerical labor	.63	.08	.08	.16
Payroll overhead (administrative)	.16	.02	.02	.04
Facilities maintenance and supplies	.07	.01	.01	.02
General overhead (including head office, charges, exploration, and research)	.15	.02	.02	.04
Subtotal indirect costs	1.01	.13	.13	.26
Total direct and indirect costs	14.92	1.53	2.24	3.77
Local taxes	1.40	.30	.05	.35
Insurance	.06	.01	.01	.02
Subtotal fixed costs	1.46	.31	.06	.37
Grand total cost	16.38	1.84	2.30	4.14

[1]Rock may or may not be dried in all cases since phosphoric acid processes are now available for the use of wet rock. Cost presented is for dry rock.

TABLE B-4. - Production cost of typical medium-sized mine in higher quality ore (case IIA)

Cost summary by category	Total operating cost per ton of product (dry, f.o.b.)	Cost per ton of ore (dry, f.o.b. mill)		
		Mine	Mill	Total
Raw materials, utilities, and support:				
Power	$2.80	$0.34	$0.51	$0.85
Reagents	1.97	0	.59	.59
Fuel (gasoline and diesel)	.05	.02	0	.02
Fuel (fuel oil drying)[1]	2.58	0	.77	.77
Supplies	.32	.07	.02	.09
Mobile mine-support equipment	.16	.05	0	.05
Outside services (dam construction and reclamation)	.59	.18	0	.18
Direct labor:				
Operating	1.54	.25	.21	.46
Supervisory	.43	.08	.05	.13
Plant maintenance:				
Labor	.53	.08	.08	.16
Supervision	.27	.04	.04	.08
Maintenance parts and supplies	1.47	.22	.22	.44
Replacement mine pipe	.18	.06	0	.06
Payroll overhead (fringes, etc.)	.64	.11	.09	.20
Subtotal direct costs	13.53	1.50	2.58	4.08
Administrative, technical, clerical labor.	.51	.08	.08	.16
Payroll overhead (administrative)	.13	.02	.02	.04
Facilities maintenance and supplies	.07	.01	.01	.02
General overhead (including head office, charges, exploration, and research)	.15	.02	.02	.04
Subtotal indirect costs	.86	.13	.13	.26
Total direct and indirect costs	14.39	1.63	2.71	4.34
Local taxes	1.40	.36	.06	.42
Insurance	.06	.01	.01	.02
Subtotal fixed costs	1.46	.37	.07	.44
Grand total cost	15.85	2.00	2.78	4.78

[1]Rock may or may not be dried in all cases since phosphoric acid processes are now available for the use of wet rock. Cost presented is for dry rock.

TABLE B-5. - Production cost of typical small mine in higher quality ore (case III)

Cost summary by category	Total operating cost per ton of product (dry, f.o.b.)	Cost per ton of ore (dry, f.o.b. mill)		
		Mine	Mill	Total
Raw materials, utilities, and support:				
Power	$2.56	$0.29	$0.43	$0.72
Reagents	1.77	0	.50	.50
Fuel (gasoline and diesel)	.08	.02	0	.02
Fuel (fuel oil drying)[1]	2.58	0	.73	.73
Supplies	.46	.10	.03	.13
Mobile mine-support equipment	.26	.07	0	.07
Outside services (dam construction and reclamation)	.70	.20	0	.20
Direct labor:				
Operating	2.31	.36	.29	.65
Supervisory	.70	.12	.08	.20
Plant maintenance:				
Labor	.76	.11	.11	.22
Supervision	.41	.06	.06	.12
Maintenance parts and supplies	2.11	.30	.30	.60
Replacement mine pipe	.47	.13	0	.13
Payroll overhead (fringes, etc.)	.97	.15	.12	.27
Subtotal direct costs	16.14	1.91	2.65	4.56
Administrative, technical, clerical labor	.83	.12	.12	.24
Payroll overhead (administrative)	.20	.03	.03	.06
Facilities maintenance and supplies	.10	.01	.01	.02
General overhead (including head office, charges, exploration, and research)	.18	.03	.03	.06
Subtotal indirect costs	1.31	.19	.19	.38
Total direct and indirect costs	17.45	2.10	2.84	4.94
Local taxes	1.40	.34	.06	.40
Insurance	.06	.01	.01	.02
Subtotal fixed costs	1.46	.35	.07	.42
Grand total cost	18.91	2.45	2.91	5.36

[1]Rock may or may not be dried in all cases since phosphoric acid processes are now available for the use of wet rock. Cost presented is for dry rock.

TABLE B-6. - Production cost of typical large mine in lower quality ore (case IV)

Cost summary by category	Total operating cost per ton of product (dry, f.o.b.)	Cost per ton of ore (dry, f.o.b. mill)		
		Mine	Mill	Total
Raw materials, utilities, and support:				
Power	$4.02	$0.26	$0.39	$0.65
Reagents	2.89	0	.47	.47
Fuel (gasoline and diesel)	.05	.01	0	.01
Fuel (fuel oil drying)[1]	2.58	0	.42	.42
Supplies	.32	.04	.01	.05
Mobile mine-support equipment	.15	.02	0	.02
Outside services (dam construction and reclamation)	.59	.10	0	.10
Direct labor:				
Operating	1.48	.13	.11	.24
Supervisory	.40	.04	.03	.07
Plant maintenance:				
Labor	.51	.04	.04	.08
Supervision	.25	.04	.02	.06
Maintenance parts and supplies	1.37	.11	.11	.22
Replacement mine pipe	.19	.03	0	.03
Payroll overhead (fringes, etc.)	.61	.06	.04	.10
Subtotal direct costs	15.41	.88	1.64	2.52
Administrative, technical, clerical labor	.48	.04	.04	.08
Payroll overhead (administrative)	.12	.01	.01	.02
Facilities maintenance and supplies	.06	.01	0	.01
General overhead (including head office, charges, exploration, and research)	.12	.01	.01	.02
Subtotal indirect costs	.78	.07	.06	.13
Total direct and indirect costs	16.19	.95	1.70	2.65
Local taxes	1.79	.25	.04	.29
Insurance	.06	.01	0	.01
Subtotal fixed costs	1.85	.26	.04	.30
Grand total cost	18.04	1.21	1.74	2.95

[1]Rock may or may not be dried in all cases since phosphoric acid processes are now available for the use of wet rock. Cost presented is for dry rock.

TABLE B-7. - Production cost of typical small mine in lower quality ore (case V)

Cost summary by category	Total operating cost per ton of product (dry, f.o.b.)	Cost per ton of ore (dry, f.o.b. mill)		
		Mine	Mill	Total
Raw materials, utilities, and support:				
Power	$2.82	$0.24	$0.37	$0.61
Reagents	2.02	0	.44	.44
Fuel (gasoline and diesel)	.08	.02	0	.02
Fuel (fuel oil drying)[1]	2.58	0	.56	.56
Supplies	.42	.07	.02	.09
Mobile mine-support equipment	.26	.06	0	.06
Outside services (dam construction and reclamation)	.81	.17	0	.17
Direct labor:				
Operating	2.15	.26	.21	.47
Supervisory	.67	.09	.06	.15
Plant maintenance:				
Labor	.75	.08	.08	.16
Supervision	.40	.04	.04	.08
Maintenance parts and supplies	2.28	.25	.36	.61
Replacement mine pipe	.22	.05	0	.05
Payroll overhead (fringes, etc.)	.92	.11	.09	.20
Subtotal direct costs	16.38	1.44	2.23	3.67
Administrative, technical, clerical labor.	.78	.08	.08	.16
Payroll overhead (administrative)	.19	.02	.02	.04
Facilities maintenance and supplies	.09	.01	.01	.02
General overhead (including head office, charges, exploration, and research)	.20	.02	.02	.04
Subtotal indirect costs	1.26	.13	.13	.26
Total direct and indirect costs	17.64	1.57	2.36	3.93
Local taxes	1.79	.33	.06	.39
Insurance	.06	.01	.01	.02
Subtotal fixed costs	1.85	.34	.07	.41
Grand total cost	19.49	1.91	2.43	4.34

[1]Rock may or may not be dried in all cases since phosphoric acid processes are now available for the use of wet rock. Cost presented is for dry rock.

Generally, the more ore that must be processed to yield a ton of product, the higher the production cost. Tables B-2 through B-7 show that the production cost for cases I through III, representing the lower matrix X ore bodies, is substantially lower than that for mines with higher matrix X ore (cases IV and V, tables B-6 and B-7). Other ore and mining factors that influence production costs are listed and briefly discussed below:

Total X. - Total X refers to the total yards of overburden plus ore that must be handled to produce a dry ton of product. Since draglines can move overburden very inexpensively, total X generally has a minor effect on production costs if the overburden is reasonably stable. If the

overburden is sufficiently thick, larger draglines may be required that increase both capital and production costs.

Concentrate-to-Pebble Ratio. - Because pebble is less expensive to produce than concentrate, ore containing pebble is usually associated with a lower production cost and better product recovery.

Matrix Clay Content. - The clay content of the ore is significant because increased clay demands more extensive waste disposal and often affects the attritionability of the ore. Tough, heavy clays can slow pumping rates, reduce production, and contaminate beneficiation products.

TABLE B-8. - Operating parameters for average mine (case I)

(3.10 million tons of product per year; 12.76 million tons of ore per year)

Production:		
Pebble...million tons..	1.77	
Total concentrate...do...	1.33	
Pebble-concentrate ratio...	1.33	
Total production...million tons..	3.10	
Mining data:		
Matrix depth...ft..	11.9	
Overburden depth...ft..	26.7	
Total depth...ft..	38.6	
Matrix density...lb/ft^3..	88.5	
Matrix X[1]...yd^3/ton product..	3.4	
Total X[2]...do...	11.1	
Tons of matrix per ton of product[3]...	4.11	
Matrix, average pumping distance...mi..	2.92	
Slimes in matrix...pct..	28	
Slimes per year...tons or acre ft..	9,880	
Tailing...million tons/yr..	6.748	
Tailings, average pumping distance...mi..	2.85	
Operating time...hr/yr..	8,760	
Number of operating days per year...	365	
Acres mined per year...	610	
Equipment data:		
Number of draglines...	2	
Size of draglines...yd^3..	45	
Number of pumping systems...	2	
Number of washer trains...	2	
Number of flotation plant trains...	2	
Number of dryers...	1	
	Mine	Mill
Operating personnel:		
Operating labor...	75	61
Direct production supervision...	25	17
Maintenance labor...	22	20
Maintenance supervision...	12	12
Technical...	15	14
General administrative...	12	12
Total...	161	136

[1]Matrix X = yd^3 of ore that must be processed to yield a ton of product.
[2]Total X = yd^3 of overburden plus ore that must be handled or processed to yield a ton of product.
[3](Matrix X)(density or tons/yd^3) = tons of matrix/ton of product.

TABLE B-9. - Operating parameters for average mine (case II)

(1.95 million tons of product per year; 7.80 million tons of ore per year)

Production:		
Pebble......million tons..		1.10
Total concentrate......do.......		.85
Pebble-concentrate ratio......		1.29
Total production......million tons..		1.95
Mining data:		
Matrix depth......ft..		16.2
Overburden depth......ft..		28.1
Total depth......ft..		44.3
Matrix density......lb/ft^3..		92.6
Matrix X[1]......yd^3/ton product..		3.2
Total X[2]......do.........		8.7
Tons of matrix per ton of product[3]......		4.00
Matrix, average pumping distance......mi..		1.94
Slimes in matrix[1]......pct..		35.0
Slimes per year......tons or acre ft..		7,959
Tailing......million tons/yr..		3.22
Tailings, average pumping distance......mi..		2.0
Operating time......hr/yr..		8,760
Number of operating days per year......		365
Acres mined per year......		263
Equipment data:		
Number of draglines......		2
Size of draglines......yd^3..		45
Number of pumping systems......		2
Number of washer trains......		2
Number of flotation plant trains......		2
Number of dryers......		1
	Mine	Mill
Operating personnel:		
Operating labor......	65	59
Direct production supervision......	23	16
Maintenance labor......	20	19
Maintenance supervision......	11	11
Technical......	14	13
General administrative......	12	11
Total......	145	129

[1]Matrix X = yd^3 of ore that must be processed to yield a ton of product.
[2]Total X = yd^3 of overburden plus ore that must be handled or processed to yield a ton of product.
[3](Matrix X)(density or tons/yd^3) = tons of matrix/ton of product.

TABLE B-10. - Operating parameters for average mine (case IIA)

(2.54 million tons of product per year; 8.58 million tons of ore per year)

Production:		
Pebble...million tons..		1.16
Total concentrate...do.......		1.38
Pebble-concentrate ratio...		.85
Total production...million tons..		2.54
Mining data:		
Matrix depth...ft..		13.0
Overburden depth...ft..		26.4
Total depth...ft..		39.5
Matrix density...lb/ft^3..		88.0
Matrix X[1]...yd^3/ton product..		2.8
Total X[2]...do.........		8.6
Tons of matrix per ton of product[3]...		3.38
Matrix, average pumping distance...mi..		2.1
Slimes in matrix...pct..		27.0
Slimes per year...tons or acre ft..		6,170
Tailing...million tons/yr..		6,076
Tailings, average pumping distance...mi..		2.0
Operating time...hr/yr..		8,760
Number of operating days per year...		365
Acres mined per year...		380
Equipment data:		
Number of draglines...		2
Size of draglines...yd^3..		45
Number of pumping systems...		2
Number of washer trains...		2
Number of flotation plant trains...		2
Number of dryers...		1
	Mine	Mill
Operating personnel:		
Operating labor...	65	59
Direct production supervision...	23	16
Maintenance labor...	20	19
Maintenance supervision...	11	11
Technical...	14	13
General administrative...	12	11
Total...	145	129

[1]Matrix X = yd^3 of ore that must be processed to yield a ton of product.

[2]Total X = yd^3 of overburden plus ore that must be handled or processed to yield a ton of product.

[3](Matrix X)(density or tons/yd^3) = tons of matrix/ton of product.

TABLE B-11. - Operating parameters for average mine (case III)

(1.12 million tons of product per year; 4.02 million tons of ore per year)

Production:		
Pebble....million tons..		0.54
Total concentrate....do.......		.58
Pebble-concentrate ratio....		.97
Total production....million tons..		1.12
Mining data:		
Matrix depth....ft..		14.6
Overburden depth....ft..		20.0
Total depth....ft..		34.6
Matrix density....lb/ft^3..		90.0
Matrix X[1]....yd^3/ton product..		2.9
Total X[2]....do........		7.1
Tons of matrix per ton of product....		3.60
Matrix, average pumping distance[3]....mi..		4.59
Slimes in matrix....pct..		39
Slimes per year....tons or acre ft..		4,098
Tailing....million tons/yr..		2.290
Tailings, average pumping distance....mi..		2.5
Operating time....hr/yr..		8,760
Number of operating days per year....		365
Acres mined per year....		156
Equipment data:		
Number of draglines....		1
Size of draglines....yd^3..		45
Number of pumping systems....		1
Number of washer trains....		1
Number of flotation plant trains....		1
Number of dryers....		1

	Mine	Mill
Operating personnel:		
Operating labor....	41	50
Direct production supervision....	16	11
Maintenance labor....	14	13
Maintenance supervision....	8	7
Technical....	11	10
General administrative....	8	8
Total....	98	99

[1]Matrix X = yd^3 of ore that must be processed to yield a ton of product.

[2]Total X = yd^3 of overburden plus ore that must be handled or processed to yield a ton of product.

[3](Matrix X)(density or tons/yd^3) = tons of matrix/ton of product.

TABLE B-12. - Operating parameters for average mine (case IV)

(2.72 million tons of product per year; 16.63 million tons of ore per year)

Production:		
Pebble..........million tons..	0.54	
Total concentrate..........do.......	2.18	
Pebble-concentrate ratio..........	.25	
Total production..........million tons..	2.72	
Mining data:		
Matrix depth..........ft..	34.2	
Overburden depth..........ft..	31.6	
Total depth..........ft..	65.8	
Matrix density..........lb/ft^3..	92.5	
Matrix X[1]..........yd^3/ton product..	4.9	
Total X[2]..........do.........	9.4	
Tons of matrix per ton of product[3]..........	6.11	
Matrix, average pumping distance..........mi..	2.25	
Slimes in matrix..........pct..	22	
Slimes per year..........tons or acre ft..	10,334	
Tailing..........million tons/yr..	7.041	
Tailings, average pumping distance..........mi..	2.25	
Operating time..........hr/yr..	8,760	
Number of operating days per year..........	365	
Acres mined per year..........	267	
Equipment data:		
Number of draglines..........	2	
Size of draglines..........yd^3..	45	
Number of pumping systems..........	2	
Number of washer trains..........	2	
Number of flotation plant trains..........	2	
Number of dryers..........	1	

	Mine	Mill
Operating personnel:		
Operating labor..........	65	59
Direct production supervision..........	23	16
Maintenance labor..........	20	19
Maintenance supervision..........	11	11
Technical..........	14	13
General administrative..........	12	11
Total..........	145	129

[1]Matrix X = yd^3 of ore that must be processed to yield a ton of product.

[2]Total X = yd^3 of overburden plus ore that must be handled or processed to yield a ton of product.

[3](Matrix X)(density or tons/yd^3) = tons of matrix/ton of product.

TABLE B-13. - Operating parameters for average mine (case V)

(1.42 million tons of product per year; 6.58 million tons of ore per year)

Production:		
Pebble....million tons..	0.56	
Total concentrate....do....	.86	
Pebble-concentrate ratio....	.65	
Total production....million tons..	1.42	
Mining data:		
Matrix depth....ft..	15.6	
Overburden depth....ft..	20.0	
Total depth....ft..	35.6	
Matrix density....lb/ft^3..	90.7	
Matrix X[1]....yd^3/ton product..	3.8	
Total X[2]....do....	9.3	
Tons of matrix per ton of product[3]....	4.62	
Matrix, average pumping distance....mi..	1.4	
Slimes in matrix....pct..	28	
Slimes per year....tons or acre ft..	5,043	
Tailing....million tons/yr..	3.198	
Tailings, average pumping distance....mi..	1.4	
Operating time....hr/yr..	8,760	
Number of operating days per year....	365	
Acres mined per year....	253	
Equipment data:		
Number of draglines....	2	
Size of draglines....yd^3..	45	
Number of pumping systems....	2	
Number of washer trains....	2	
Number of flotation plant trains....	2	
Number of dryers....	1	
	Mine	**Mill**
Operating personnel:		
Operating labor....	57	56
Direct production supervision....	21	14
Maintenance labor....	18	17
Maintenance supervision....	10	10
Technical....	13	12
General administrative....	11	10
Total....	130	119

[1]Matrix X = yd^3 of ore that must be processed to yield a ton of product.

[2]Total X = yd^3 of overburden plus ore that must be handled or processed to yield a ton of product.

[3](Matrix X)(density or tons/yd^3) = tons of matrix/ton of product.

Feed Grade. - Feed grade refers to the P_2O_5 concentration of the sand-size material in the ore. Generally the higher the feed grade, the lower the reagent cost incurred in the producing a ton of concentrate.

Total Depth. - Total depth, the total depth in the operating pit, is the sum of the overburden and ore thickness. Generally the effect of total depth on production costs is minor up to depths of 70 to 80 ft. Greater depths, however, increase costs through overburden rehandling or larger capital expenditures for draglines.

Contaminant Content of Ore. - Magnesium and insoluble iron and aluminum content of the ore also affect production cost. Dolomitic fragments or coating may cause problems in feed preparation or flotation; high insoluble levels may cause flotation difficulties. High product-contaminant content may increase production cost per ton through the exclusion of otherwise suitable ore or through additional process requirements to make the product acceptable.

Production rate is the second major factor affecting production costs. Many cost inputs into a mining operation are not directly proportional to size. As the production rate increases, the cost per ton for these relatively fixed costs decreases. All other factors being equal, larger mines in volume of production have the cost advantage. Tables B-2 through B-7 show the definite correlation between mine size and production cost.

Capital Costs

Capital costs, estimated or based on known data, are summarized in tables B-14 and B-15. The costs are for nonproducing deposits (cases IV and V) in January 1981 dollars. Capital-cost estimates for producing operations (in book value as of January 1978) are detailed elsewhere (20).

Capital outlay can have a profound influence on unit production costs, as related to interest on invested capital and depreciation of capital facilities. Capital requirements for ore, equipment, and facilities have escalated rapidly in recent years; therefore, existing mines will incur interest and depreciation expenses on a much smaller base than newer or proposed mines. The initial capital investment on many existing mines has been largely depreciated. This depreciation was largely responsible for separating the higher production costs for the new existing mines grouped as case IIA from those of the older mines with otherwise similar characteristics grouped in case II.

Other miscellaneous factors also influence production costs. Long pumping distances, requiring heavy expenditures for power, pumps, and pipe, force production costs upward. Mine recovery, the percentage of the ore recovered from the mining pit, markedly affects total project economics through its influence on actual reserve costs and mine life. Although influencing the frequency of pit moves, production rate, etc., mine recovery is generally not a recognized major factor in direct production costs.

TABLE B-14. - Capital costs of typical large mine in lower quality ore (case IV)

	Capital cost, million dollars
Mine area:	
Roads	0.4
Utilities	5.2
Buildings	.4
Mine equipment:	
Prime movers (draglines)	19.1
Hydraulic water and ore transportation	9.6
Mine-support equipment	1.9
Miscellaneous	1.2
Subtotal mine capital	37.8
Exploration and development	3.7
Land acquisition (land reserves cost)	48.2
Permitting and environmental	1.1
Working capital (90 days)	5.5
Subtotal other capital	58.5
Total mine capital	96.3
Mill area:	
Roads	.5
Utilities	2.5
Buildings (office only)	1.0
Process units:[1]	
Washer	22.2
Feed preparation	7.4
Reagent storage	4.9
Flotation	28.4
Water distribution and waste disposal	3.7
Wet-rock storage, drying, and shipping	7.4
Offsites[2]	6.7
Subtotal mill capital	84.7
Working capital (90 days)	12.6
Permitting and environmental	0
Subtotal other capital	12.6
Total mill	97.3
Grand total mine and mill	193.6

[1]Complete units including equipment ready to operate.
[2]Support facilities--shops, rails, laboratory, etc.

TABLE B-15. - Capital costs of typical large mine in lower quality ore (case V)

	Capital cost, million dollars
Mine area:	
Roads	0.2
Utilities	3.1
Buildings	.2
Mine equipment:	
Prime movers (draglines)	11.4
Hydraulic water and ore transportation	5.7
Mine-support equipment	1.1
Miscellaneous	.7
Subtotal mine capital	22.4
Exploration and development	2.9
Land acquisition (land reserves cost)	38.0
Permitting and environmental	.8
Working capital (90 days)	3.4
Subtotal other capital	45.1
Total mine capital	67.5
Mill area:	
Roads	.3
Utilities	1.5
Buildings (office only)	.6
Process units:[1]	
Washer	13.2
Feed preparation	4.4
Reagent storage	2.9
Flotation	16.9
Water distribution and waste disposal	2.2
Wet-rock storage, drying, and shipping	4.4
Offsites[2]	4.0
Subtotal mill capital	50.4
Working capital (90 days)	7.8
Permitting and environmental	0
Subtotal other capital	7.8
Total mill	58.2
Grand total mine and mill	125.7

[1]Complete units including equipment ready to operate.
[2]Support facilities--shops, rails, laboratory, etc.

APPENDIX C.--DOMESTIC PHOSPHATE REGULATORY AND ENVIRONMENTAL CONSTRAINTS AND PERMITTING

Starting up a phosphate mining operation in the United States has become increasingly more difficult and time consuming in recent years (particularly in Florida) because of regulatory requirements, environmental studies, and lengthy permitting procedures.

A number of environmental and regulatory constraints developed in Florida over recent years reflect the public's concern that strip mining is a potential threat to two of the State's major industries: tourism and agriculture. Issues of major concern to the public and, consequently, the State government include land aesthetics, productivity of the reclaimed land (most is now used by the agricultural industry), disruption of wildlife habitats and wetlands, clay waste disposal methods (slime ponds), extensive water usage, and radiation levels in overburden spoils, reclaimed soils, and sand-clay wastes. (Radiation is due to the uranium and its decay products associated with phosphate rock.)

The industry must follow an extensive permitting process to start a Florida phosphate operation. These permits force the mining companies to address those issues previously discussed. The permits, developed at all levels of government (county, State, and Federal), are listed below. This extensive permitting is a result of public and governmental concern for the impact of mining on the local environment, economy, and culture. A detailed description of these permits appears in the Zellars-Williams MAS report on Florida phosphate availability (20).

It should also be noted that present operating mines are being required to comply with many parameters included in these permits.

The following is a list of most of the major permits required to develop a phosphate operation in Florida:

County

Zoning Change
Master Plan Approval
Development Order
Operating Permit
Building Permit

State

Division of State Planning (through Regional Planning Council): Development of Regional Impact
Department of Environmental Regulation:
- Air Quality Permit
- Industrial Waste Water Permit
- Dredge and Fill Permit
- Drainage Well Permit
- Dam Construction Permit
- Potable Water Supply Permit
- Sanitary Waste Permit

Water Management District:
- Consumptive Water Use Permit
- Water Well Construction Permit
- Works of the District Permit

Department of Natural Resources: Reclamation Standards

Federal

Environmental Protection Agency:
- NPDES (Water Quality) Permit
- Air Quality Standards

Army Corps of Engineers:
- Dredge and Fill Permit
- Dam Construction in Waters of the United States Permit

The environmental and regulatory constraints in the western field phosphate deposits are not so complex as those in Florida. Because nearly all phosphate deposits in the Western United States are within Federal lands, the right to mine these deposits must be obtained through a Federal lease agreement. These lease agreements specify a limit to the size of the mining operation, a rental fee (per acre), and a royalty. Leases are obtained through the U.S. Bureau of Land Management; development, mining, and reclamation activities are supervised by the U.S. Geological Survey. The U.S. Forest Service is involved when lands it administers are leased. Environmental impact statements are often also written before leasing a deposit. Numerous other State and Federal agencies can be included in the supervision of a phosphate mining lease.

Certain environmental constraints exist in the western fields, including reclamation of pits and waste dumps, revegetation of the mine site, and preservation of water quality.

Some of the Western States have more stringent regultations than others concerning regulations and environmental quality.

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